STRP
PRSTC

Strategic Transit
Research Program

Programme de recherche
stratégique de
transport en commun

STRP Report 11

Low-Floor Bus Climate Control System (CCS):

Summary of Findings from Climate Control Tests, and CCS Performance Specifications Guidelines and Test Procedures

a project managed by
un projet dirigé par

cuta actu

Canadian Urban Transit Association
Association canadienne du transport urbain

The Strategic Transit Research Program (STRP) is a National cooperative research program for the Canadian urban transit industry. This program is coordinated and managed by the Canadian Urban Transit Association (CUTA), and has been made possible through the financial support of the following organizations:

Le programme de recherche stratégique de transport en commun (PRSTC) est un programme national et coopératif de recherche pour l'industrie du transport en commun au Canada. La coordination et gestion de ce programme est assurée par l'Association canadienne du transport urbain. Le programme est rendu possible par le soutien financier des organisations suivantes:

TRANSPORT CANADA / TRANSPORTS CANADA

MINISTÈRE DES TRANSPORTS DU QUÉBEC
MINISTRY OF TRANSPORTATION OF ONTARIO

SOCIÉTÉ DE TRANSPORT DE LA COMMUNAUTÉ URBAINE DE MONTRÉAL
OTTAWA-CARLETON REGIONAL TRANSIT COMMISSION
EDMONTON TRANSIT
CALGARY TRANSIT
WINNIPEG TRANSIT
COMMISSION DE TRANSPORT DE LA COMMUNAUTÉ URBAINE DE QUÉBEC
HAMILTON STREET RAILWAY
MISSISSAUGA TRANSIT
SOCIÉTÉ DE TRANSPORT DE LA VILLE DE LAVAL
LONDON TRANSIT COMMISSION
HALIFAX REGIONAL MUNICIPALITY
SOCIÉTÉ DE TRANSPORT DE L'OUTAOUAIS

Canadian Urban Transit Association
Association canadienne du transport urbain

Tel: (416) 365-9800
Fax: (416) 365-1295
E-mail / courriel : transit@cutaactu.on.ca
Web : www.cutaactu.on.ca

101-02580/

cuta actu
Canadian Urban Transit Association
Association canadienne du transport urbain

STRP Report 11

Low-Floor Bus Climate Control System (CCS):

Summary of Findings from Climate Control Tests, and CCS Performance Specifications Guidelines and Test Procedures

Prepared by:

Rolland King

May 1999

CUTA Mission Statement

CUTA is the association of providers of urban transit services, suppliers and related organizations in Canada. Its mission is to promote the role of urban transit in enhancing mobility, and to support its members in the fulfilment of their mandate.

Disclaimer

The contents of this report reflect the views of the author(s) based on their research, but do not necessarily reflect the official views or opinions of the Canadian Urban Transit Association, nor of the organizations funding the Strategic Transit Research Program.

Printed and bound in Canada

Toronto, 2000

STRP 11
ISBN 0-920559-34-4

CUTA REPORT DOCUMENTATION FORM

CUTA Report No.	ISBN No.	Publication Date
STRP 11	0-920559-34-4	May 1999

Title and Sub-Title

Low-Floor Bus Climate Control System (CCS): Summary of Findings from Climate Control Tests, and CCS Performance Specifications Guidelines and Test Procedures

Author

Rolland King

Performing Agency

1266 Southport Circle
Columbus, OH 43235
Tel: (614) 451-4195
<Tordking@aol.com>

Project Manager

Brendon Hemily, Ph.D.
Manager of Research and Technical Services
Canadian Urban Transit Association

Sponsoring Agency

Canadian Urban Transit Association (CUTA)
55 York Street, Suite 901
Toronto, Canada M5J 1R7
Tel: (416) 365-9800
<transit@cutaactu.on.ca>

Supplementary Notes

This report was prepared under CUTA's Strategic Transit Research Program which is co-funded by Transport Canada, the provinces of Quebec and Ontario, and twelve local transit systems.

Abstract

Previous STRP studies exploring the Interior Bus Design (STRP 2 and 7) identified a number of issues and concerns relating to ventilation and/or climate control (both heating and cooling) on urban buses. These concerns were amplified with the introduction of low-floor bus designs, which drastically replaced existing proven heating system designs (e.g. the warm-wall design), with new designs relying primarily on overhead distribution. As a result CUTA conducted a wide range of ventilation and climate control tests, and worked to define new performance-based standards. This report synthesizes these efforts.

In Part 1, the report summarizes the key findings of the various bus ventilation and climate control tests carried out from 1993 to 1996; the detailed results of these tests are documented in STRP Report 11A. This Summary reports on key findings from these tests with respect to make-up air, bus passenger area temperatures, driver area temperatures, carbon dioxide, carbon monoxide, and temperature impacts of door openings. The report identifies a number of issues, in particular by comparing the test results to standards established by ASHRAE and other bodies.

Part 2 contains the "Low-Floor Bus Climate Control System (CCS) Performance Specifications Guidelines and Test Procedures". In Part A, the CCS Specification Guidelines, define the performance requirements for the CCS, which cover all of the equipment required to provide heating and ventilation (and optional cooling) of the bus, as well as the control of these functions for the comfort of all occupants. The goal is to ensure that the bus is equipped with an integrated CCS that automatically adjusts the amount of heated, cooled, or make up air (MUA) entering and exiting the interior of the bus. The system shall provide sufficient volumes of heated, cooled, or make up air uniformly distributed, and at velocities and locations, that meet commonly accepted physiological needs for a comfortable healthy environment.

Finally, in Part B, the report outlines specific Test Procedures that can be applied to ensure that a bus model meets the recommended CCS Specification Guidelines.

Key Words	Language
Urban Bus Design; Ventilation; Climate Control; Interior Air Quality	English. (Ce rapport sera aussi disponible en français)
No. of Pages: 86	Distribution: This report is available from CUTA.

ACKNOWLEDGEMENTS

We would like to thank the consultants for their very professional contributions to the various phases of the multi-year STRP Urban Bus Ventilation and Climate Control Study. More specifically, the consultants for this study were: **Malcolm Morris of ENVIROTEST Inc.**, who performed the actual empirical tests (STRP Report 11A), and **Rollie King** of Columbus Ohio, who prepared the Summary of Findings and CCS Performance Guidelines and Test Procedures (STRP Report 11).

We would also like to thank all of the members of the **CUTA Bus Design and Maintenance Committee** who contributed many hours to reviewing, and discussing during committee conference calls and meetings, the many reports that emerged from this multi-year study. Several Committee members, such as Philippe Coutu, Donald Deschênes, Roy Duncan, Richard Ferguson, Dave Geake, Bob Kirkpatrick, Al Little, Gary Strachan, and Ferdinand Wolff, went beyond the call of duty for this particular study.

Special thanks are given to **Toivo Madrus** of GO Transit, for his efforts during the initiation of the project, **Adrian Wright** of OC Transpo, for his assistance with the tests in Ottawa, and **Claude Guérette** of the Transportation Development Centre (TDC) of Transport Canada, who was actively involved throughout the CUTA study, and was instrumental in the conduct of two important subsequent test on NovaBUS LFS buses.

However, we would also like to highlight the fact that the pursuit of the this STRP study would not have been feasible without the tireless investment of time and effort by two particular individuals: **Paul Davidson**, of GO Transit, and **Peter *("Warmwall")* Newgard,** of OC Transpo. Both ensured the availability of the facilities and vehicles, at GO and OC Transpo respectively, for the tests. More importantly, Paul provided his expertise to devise appropriate testing procedures, to manage the set-up and data extraction from the Data Logger loaned to the study on numerous occasions by GO Transit, and spent many, many hours ensuring that the tests went smoothly and reviewing reports. And of course, "Warmwall" Newgard, the first Chair of the Bus Design and Maintenance Committee, was perhaps the individual who was the most concerned about the entire issue of climate control and its impacts on transit customers and bus operators. His tenacious interest and keen involvement throughout the study were critical.

All of these efforts have resulted in some truly groundbreaking research, but more importantly, has stimulated significant actual improvements to the ventilation and climate control systems in some recent Canadian bus models. This will be of real benefit to our customers. It has been a pleasure working with all of you over this multi-year project.

Brendon Hemily, Ph.D.

URBAN BUS VENTILATION AND CLIMATE CONTROL STUDY:

Summary of Findings

Prepared by:

Rolland King

October 1997
(Revised May 1999)

EXECUTIVE SUMMARY OF FINDINGS

URBAN BUS VENTILATION AND CLIMATE CONTROL STUDY TESTS

The following are the key findings of the tests of low-floor buses conducted by CUTA and Transport Canada.

- MAKE UP AIR (MUA)

  - Only one of the low-floor buses tested met the ASHRAE Standard (15 cfm per occupant) for fresh air using the passenger system heating and ventilation system on high speed setting. All but one met the Standard when both the driver and passenger systems were on high speed conditions.

- PASSENGER COMPARTMENT TEMPERATURES

  - None of the low-floor buses tested controlled temperatures within the range recommended by ASHRAE for winter clothing (67.7 to 76.3 °F).

  - None of the low-floor buses tested met the ASRAE recommended vertical temperature differential of 5°F for all areas of the bus.

  - The measured horizontal differential temperatures for the head zone ranged from 8 °F to 17 °F, and for the foot zone ranged from 10 °F to 23 °F for the five low-floor buses tested.

- CO AND CO_2

  - The measurements made on the high-floor buses seem to indicate that there should be no problems with meeting the recommended levels for CO and CO_2 so long as the recommended ASHRAE level for MUA is provided. All of the high-floor buses tested were well within the recommended CO levels in spite of their lower than recommended MUA capability. One of the tested buses met the CO_2 "fresh air" standard with one-half the recommended MUA capability.

TABLE OF CONTENTS

I	BACKGROUND	1
II	TEST PROGRAM	3
III	DISCUSSION OF TEST RESULTS	5
	1. Discussion of Tests of High Floor Buses	5
	2. Discussion of Tests of Low-Floor Buses	9
IV	OVERALL STUDY FINDINGS	13
	1. Make Up Air (MUA)	13
	2. Bus Passenger Area Temperatures	14
	3. Driver Area Temperatures	16
	4. Carbon Dioxide Levels	17
	5. Carbon Monoxide Levels	18
	6. Temperature Impacts of Door Openings	19
BIBLIOGRAPHY		23
APPENDIX A -- DESCRIPTION OF TEST BUSES		25
APPENDIX B -- DESCRIPTION OF TEST INSTRUMENTATION		35
APPENDIX C -- SECOND TEST OF THE NOVA BUS LFS		37
APPENDIX D -- ORION VI WARM WALL PROTOTYPE TEST		41

URBAN BUS VENTILATION AND CLIMATE CONTROL STUDY: Summary of Findings

I BACKGROUND

The Canadian Urban Transit Association (CUTA) had identified in 1988 during a special workshop on urban bus design improvements the need to explore issues related to the design of the passenger environment on urban buses, in order to improve the comfort of transit customers.

Two studies have been conducted in 1991 and 1992 as part of CUTA's Strategic Transit Research Program (STRP) that have focused on the issue. These are:

Customer Perspectives on Interior Bus Design Issues: An Analysis Based on Focus Groups (STRP 2), which used sixteen focus groups in six cities to better understand customer needs with respect to interior bus design.

Industry Perspectives on Interior Bus Design Issues: Background Research on Current Practice and Issues (STRP 7), which used interviews with 30 transit equipment staff and representatives from suppliers to outline current practice and issues.

Based on the findings of these two studies, and of discussions held during the special Bus Design Workshop in November 1992 in Laval, a need emerged to focus more attention to the issue of passenger environment comfort (primarily climate control, and possibly noise and air quality as well). In particular, there appears a need to define appropriate standards and standardized testing protocols. Initial research indicated that the only area where standards existed related to the performance of the transit bus air conditioning system (the "Pull-Down Heat Test" developed by Houston Metro). In addition, it was found that there were little, if any, empirical data that would allow one to assess the existing performance of urban bus ventilation and climate control systems. Obtaining such data was a critical step in the development of customer environmental comfort standards.

The project goals were thus defined as:

1) to conduct a series of empirical tests on various types of urban buses in an effort to measure their performance of the ventilation and heating systems, and interior air quality,

2) to develop a standard for customer environmental comfort on urban buses with respect to the ventilation and climate control systems (in particular heating), and

3) to develop a practical standardized protocol that can be used by transit systems and Original Equipment Manufacturers (OEM's) for measuring performance related to the above standard.

This research gained added importance with the development and increasingly widespread implementation of low-floor buses. The design approach for the heating and ventilation systems for the new low-floor buses had to be different than what had been used for the conventional high floor buses. Since there was not room under the bus for heating and ventilation equipment, all equipment was located in the roof area of the bus. Generally, the supply air was provided through vents above the windows in the ceiling area, and the return air openings were also located in the ceiling area. For some of the low-floor buses, radiant heaters were located at the floor level in the passenger area.

During winter conditions, the comfort of these new low-floor buses was not as good as with the high floor buses. During the initial years there were complaints from passengers expressing their dissatisfaction with the heating and ventilation of the buses. CUTA's ongoing research provided an avenue for understanding and addressing this issue, and low-floor bus tests were incorporated into the research.

II TEST PROGRAM

A contract was made with Envirotest, Inc. to conduct a series of tests, first on several models of representative high floor buses, and subsequently on low-floor buses models offered by the three bus manufacturers. The purpose of these tests was to gather objective and quantitative data with respect to the effectiveness of the mechanical ventilation and heating systems of standard length transit buses. In addition, these tests might provide a foundation on which to develop a test procedure for the acceptance testing of the heating and ventilation systems of low-floor buses.

The program was conducted in five phases. In **Phase 1**, the basic test procedures were developed and performed on four high-floor buses. These buses were; a New Flyer Industries Limited (NFIL) 1991 D 40 Suburban, a NFIL 1992 D 40, an Orion Bus Industries (OBI) 1992 Orion V, and a General Motors Corporation (GMC) 1987 Classic. The major goals of these tests were to develop a testing protocol, to establish the test instrumentation including the construction of some adapters and test apparatus, and to gain some experience in performing heating and ventilation tests. These tests were performed during June of 1993. Measurements were made of the supply, return, and make up air flows and of temperatures in several locations in the passenger and driver areas. The effects of passenger loads were not directly measured during this series of tests. However, calculations were made of the heat load and moisture gain for the passenger area based upon the seated load capacity of each bus.

Phase 2 followed in January 1994, with tests under winter conditions on three of the current high floor buses. Tests were not conducted on the GMC Classic. One of the goals of these tests was to establish a baseline set of data of passenger area and driver area head zone and foot zone temperatures for high-floor buses. Test runs were made with both no passengers, and with a partial passenger load. Measurements were made of the impacts of opening of the entrance and rear doors on the temperatures in the bus. Also, measurements were made of the relative humidity, CO_2 and CO levels in the passenger area of the bus.

Phases 3, 4, and 5 involved tests on the low-floor bus models of the three bus manufacturers. In Phase 3, a NFIL D 40 LF bus was tested in January 1995. Phase 4 involved the testing of two prototype models of the OBI Orion VI bus in January-

February 1996. One was a three door model and the other a two door model. Phase 5, conducted on behalf of the Transportation Development Centre of Transport Canada, involved using the same methodology and equipment to testing a Nova Bus LSF bus, in March 1996. The buses for Phases 3 and 4 were tested at the OC Transpo facility in Ottawa, Ontario, and for Phase 5 the bus was tested at Environment Canada's Environmental Technology Centre in Ottawa, Ontario. Measurements were made of the supply, return, and make up air flows, and of head zone and foot zone temperatures at various locations in the passenger and driver areas.

A brief description of the heating and ventilation systems for each of the test buses is provided in Appendix A. Appendix B provides information on the test instruments and test equipment that were used during the tests.

Two other sets of bus tests, using the same testing methodology, equipment, and consultant, were conducted subsequent to the preparation of the initial version of this report. One involved a test with a different Nova Bus LFS in March 1998, and the other involved a test in February 1997 of an Orion VI equipped with a prototype warm wall concept. The results from these tests have not been incorporated into this report because it was felt that they did not alter the report's key findings. However, brief descriptions of these two subsequent tests can be found in Appendices C & D.

The complete test results are referenced in the Bibliography. The project reports for the Phase 1 to 4 tests have been published as STRP Report 11A, entitled **Urban Bus Ventilation and Climate Control Study: Test Results**.

III DISCUSSION OF TEST RESULTS

Tests were performed on high-floor buses during Phases 1 and 2, and on low-floor buses during Phases 3, 4, and 5. During Phase 1 the methodology for collecting the desired air flows, temperatures, and air movement patterns data was developed. During Phase 2 measurements were made of temperatures, CO and CO_2 levels, and relative humidity in the passenger area. During Phases 3, 4, and 5, measurements were made of air flows in the passenger and driver areas (as was done in Phase 1) and of temperatures in the passenger and driver areas (as was done in Phase 2).

1. Discussion of Tests of High Floor Buses

During Phases 1 and 2, tests were conducted on high-floor buses to develop a baseline set of measurements which then could be compared to the measurements obtained from the low-floor buses. Information on these test buses, and their heating and ventilation systems is given in Appendix A. The Phase 1 tests were conducted during the Summer of 1993 at the GO Transit, OC Transpo, and Toronto Transit Commission (TTC) facilities. The Phase 2 tests were conducted during the Winter of 1994 at the OC Transpo facilities.

a) Discussion of Phase 1 Tests

Data were gathered with respect to the mechanical ventilation effectiveness serving the passenger and driver areas of four different high-floor buses during Phase 1. Because of the large amount of data collected it was reported in graphical format. Using the test instrumentation described in Appendix B, data were collected of air flow velocities and volumes and temperatures in the passenger and driver areas. Heat gain and moisture gain to the ventilated air was calculated based on standards from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Data were collected for both bus stationary (with both "doors and windows closed" and "simulated door open intervals" conditions), and for bus moving conditions.

Table 1 provides a summary of the data collected for each of the four test buses. One of the test buses was a suburban model with one door. The other three buses

Table 1. Information on Test Data for Baseline Buses -- Summer Conditions (Phase 1)

BUS IDENTIFICATION MANUF., YR., & MODEL NUMBER NUMBER OF SEATED PASSENGERS TRANSIT AUTHORITY	N.F.I.L. 1991 D40 S 49 GO TRANSIT # 1915	N.F.I.L. 1992 D40 48 OC TRANSPO #9221	OBI ORION 5 1992 46 OC TRANSPO #9249	GMC CLASSIC 1987 40 TTC #6251
DATE OF TESTS	June 4, 1993	June 21, 1993	June 22, 1993	June 28, 1993
AMBIENT TEMPERATURE	63 ° F	74 ° F	65 ° F	78 ° F
RELATIVE HUMIDITY	51 %	50 %	30 %	52 %
SUPPLY AIR FLOW PASSENGER AREA - scfm PASSENGER AREA - lb air/hr PER PASSENGER - cfm PASSENGER + DRIVER - cfm PER OCCUPANT - cfm	HVAC (HS) 1,905 ° 8,404# 38.9° 2,588° 51.8°	HV (HS) AC (HS) 1,435 2,085 6,474# 9,406 29.9 43.4 2,135 ° not provided 43.6°	HV (HS) AC (HS) 1,135 2,385 5,120# 10,841# 24.7 51.8 1,881° not provided 40.0°	HV (one speed) 1,180 5,934 29.5 1,630° 50.7°
MAKE UP AIR (MUA) PER PASSENGER - cfm PERCENT OF SUPPLY - % PASSENGER + DRIVER - cfm PER OCCUPANT - cfm PERCENT OF SUPPLY - %	HVAC 0.6 1.6 490° 9.8° 18.9°	HV AC 7.9 2.8 27 6.6 480° not provided 9.8° 22.5°	HV AC 4 2.8 16 5.4 685 ° not provided 14.6° 36.4°	HV 3.9 13.1 380° 9.3° 23.3°
HEAT GAIN DUE TO PASSENGERS ENTHALPY, h , Btu/lb air HEAT INCREASE, PERCENT TOTAL - %	HVAC 2.39° # 10.0° #	AC 2.19 9.8 #	AC 1.88# 10.4 #	HV 3.04# 9.9#
MOISTURE GAIN DUE TO PASS. INCREMENTAL GAIN - lb H_2O/lb air OVERALL INCREASE - %	HVAC 0.00041° # 6.7° #	AC 0.00033 3.3	AC 0.00026# 6.5#	HV 0.0013 14.3
COACH TEMPERATURES (PASS.)[a,b] ° F RANGE FRONT TO BACK (Head) - ° F RANGE FRONT TO BACK (Foot) - ° F	Average -- 72.3° 71.9 to 75.3° (Δ = 3.4) 70 to 75.4° (Δ = 5.4)	Average -- 60.4° 57.7 to 62° (Δ = 4.3) 57.7 to 61.5° (Δ = 3.8)	Average -- 58.4 ° 54.2 to 59.1° (Δ = 4.9) 57.1 to 61.9° (Δ = 4.8)	Est. Avg. -- 86.5° (b) 87.3 to 86.2° (middle) (Δ = 1.1) 84.7 to 88.7° (Δ = 4.0)

° Based on information given in the Charts, which in a few cases differed from the information given in the text. (a) Passenger AC on and driver AC off.

Calculated from data. (b) Passenger HV system on driver HV system off.

were two door city buses. The ambient temperatures for these tests ranged from 63 to 78 °F, and the ambient relative humidity (RH) ranged from 30 to 52%.

The supply air flow per passenger ranged from 24.7 cubic feet per minute (cfm) to 51.8 cfm. The Make Up Air (MUA) per occupant with both passenger and driver ventilation systems set to high speed ranged from 9.3 to 14.6 cfm.

The calculated heat gains for a seated passenger load ranged from 9.8% to 10.4% which was reported as a condition that would have an effect on the quality of the ventilated air in the coach. The moisture gains for a seated passenger load ranged from 3.3% to 14.3%. The lower moisture gains were conditions that would not have an effect on the quality of the ventilated air in the coach, however, the higher moisture gains were conditions that were expected to have a significant effect on the quality of the ventilated air.

b) Discussion of Phase 2 Tests

During Phase 2 data were gathered with respect to the mechanical and heating effectiveness serving the passenger and driver areas of three high-floor buses under Winter conditions. These buses were the same models tested in Phase 1. The data was reported in graphical format because of the volume of data collected. Using the test instrumentation described in Appendix B, data were collected on coach temperatures for head zones and foot zones in the passenger and driver areas. In addition, CO and CO_2 measurements were taken. The test conditions included: bus stationary, bus in motion, empty and partial passenger loads, and various door open times.

Table 2 provides a summary of the data collected for each of the three test buses. One bus is a single door suburban model, the other two were two door city buses. The outside ambient temperatures for these tests ranged from 18 to 31 ° F, and the outside ambient RH ranged from 52 to 66%.

Table 2. Information on Test Data for Baseline Buses -- Winter Conditions (Phase 2)

BUS IDENTIFICATION MANUF., YEAR, & MODEL NUMBER NUMBER OF SEATED PASSENGERS TRANSIT AUTHORITY	N.F.I.L. 1991 D40 S 49 GO TRANSIT # 1904	N.F.I.L. 1992 D40 48 OC TRANSPO #9222	OBI ORION 5 1992 46 OC TRANSPO #9237
DATE OF TESTS	January 25, 1994	March 9, 1994	March 10, 1994
AMBIENT TEMPERATURE	21 ° F - no load test 18 ° F - partial load test	30 ° F - no load test 23 ° F - partial load test	31 ° F - no load test 31 ° F - partial load test
RELATIVE HUMIDITY -- AMBIENT PASSENGER AREA (Partial load test)	66 % Mean suppply 4.9 % Mean return 18.1 % °	52 % Mean suppply 4.9 % Mean return 8.1 % °	52 % Mean suppply 10 % Mean return 27 % °
COACH TEMPERATURES (No load test) - ° F HEAD ZONE RANGE FRONT TO BACK - ° F FOOT ZONE RANGE FRONT TO BACK - ° F VARIATION, SIDE TO SIDE (Head zone) - ° F HEAD ZONE TO FOOT ZONE DIFFERENTIAL - °F	Mean Supply -- 86.9 Mean Return -- 78.3 94 to 73 ° (Δ = 21) 91 to 75 ° (Δ = 24) Δ = 1 to 7 ° = 3 (except first seats = 7 & 18)	Mean Supply -- 83.1 Mean Return -- 74.8 80 fr., 72 mid., & 74 bk° (Δ = 8) 79 fr., 73 mid., & 77 bk ° (Δ = 6) Δ = 1 to 6 ° = 4 (except seat 1 = 7)	Mean Supply -- 93.1 Mean Return -- 74.1 84 fr., 73 mid. & 75 bk ° (Δ = 11) 70 fr., 68 mid. & 71 bk ° (Δ = 2) Δ = 1 to 2° = 5 (except seat 1 = 11)
DOOR OPENINGS TEMPERATURE IMPACTS NEAR BY PASSENGER SEATS - ° F DRIVER AREA - °F DURATION OF IMPACT	5 to 10 max. drop (20 sec. opening) 32 max. drop (20 sec. opening) = I Minute °	= 29 max. drop (40 seconds) = 20 max. drop (40 seconds) = 2 Minutes °	= 17 max. drop (90 seconds)# = 30 max. drop (90 seconds)# = 2 Minutes °
MAKE UP AIR (MUA) (Estimates) BASED ON CO_2 DATA - % BASED ON AIR TEMPERATURES - %	MUA = 9 MUA = 5	MUA = 2 MUA = 8	MUA = 30 MUA = 45
CO_2 MEASUREMENTS Mean values (partial load)	975 ppm (Return) 925 ppm (Supply)	598 ppm - Return 603 ppm -- Supply	641 ppm - Return 550 ppm - Supply
CO MEASUREMENTS NO LOAD TEST PARTIAL LOAD TEST	Mean of 2 ppm and Peak of 5 ppm Mean of 2 ppm and Peak of 7 ppm	Mean of 1 ppm and Peak of 5 ppm Mean of 8 ppm and Peak of 10 ppm	Not provided Mean of 7 ppm and Peak of 16 ppm

Questionable data because of equipment malfunction.

° Data obtained from the charts

The head zone temperatures for the passenger area ranged from 72 to 94° F (_ = 22° F) and the foot zone temperatures ranged from 68 to 91° F (_ = 23° F). The temperature variation from side to side ranged from 1 to 2 ° F for one coach to 1 to 7 ° F for another coach. The differential between head zone and foot zone temperatures were 3 to 5 ° F, except for a few seats near the driver area.

As expected the impact of door openings was most significant on the driver area and seats near an open door. The temperature drops for the driver foot zone ranged from a maximum of 32 ° F for a 20 second door opening with an outside ambient temperature of 21 ° F to 20 ° F drop for a 40 second door opening with an outside ambient temperature of 30 ° F. The duration of these temperature drops ranged from about one minute for a 20-second door opening to about two minutes for a 90-second door opening.

The mean return air CO_2 level measurements ranged from 598 (parts per million) ppm to 975 ppm. A mean level of 975 ppm have been shown to be associated with consistent complaints regarding air quality from sedentary people. The mean return air CO level measurements ranged from 2 ppm to 8 ppm, with peak levels up to 16 ppm. These levels are below the Ministry of Labor guidelines.

The mean RH measured at the supply air ranged from 5 to 10 %. These levels are considerably below the ASHRAE recommended levels of 30 to 50% to provide adequate passenger comfort in winter conditions.

2. Discussion of Tests of Low-Floor Buses

During Phases 3, 4, and 5, tests on four low-floor buses were conducted under Winter conditions during the period of January to March of 1996. Table 3 contains a summary of the data collected on the four buses. Three of the buses are two door buses and one bus had three doors. The outside ambient temperatures ranged from 15 to 23° F.

Table 3. Information of Test Data for Low-Floor Buses -- Winter Conditions (Phases 3, 4, and 5)

BUS IDENTIFICATION MANUF., YR., & MODEL NUMBER NUMBER OF SEATED PASSENGERS TRANSIT AUTHORITY	N.F.I.L. 1992 D40 LF 38 OC TRANSPO # 92011	OBI ORION VI (prototype) 33 LONDON TRANSIT #1710	OBI ORION VI (prototype) 28 (3 doors) OC TRANSPO #1711	NOVA BUS LFS 39 STCUM # 16-002
DATE OF TESTS	January 26, 1995	January 29, 1996	February 1, 1996	March 28 and 29, 1996
AMBIENT TEMPERATURE	23 ° F	15 ° F	15 ° F	12 to 18 ° F
SUPPLY AIR FLOW[a] PASSENGER AREA - scfm PER PASSENGER - cfm (seated) PASSENGER + DRIVER – scfm PER OCCUPANT - cfm	LI[a] HI[a] 880 1,440 23.1 37.9 1,010 2,035 25.9 52.2	LS HS 1,320 2,030 40 61.5 1,740 2,670 51.2 78.5	LS HS 1,620 2,530 57.8 90.4 2,140 ° 3,200 97 110	LS HS 2,100 2,750 53.8 70.5 2,315 3,200 57.9 80
MAKE UP AIR (MUA)[a] PASSENGER AREA – cfm PER PASSENGER – cfm PERCENT OF SUPPLY - % PASSENGER + DRIVER – cfm PER OCCUPANT - cfm PERCENT OF SUPPLY - %	LI HI 95 125 ° 2.5 3.3 10.7 8.7 185 350 4.7 9.0 18.3 17.2	LS HS 10 17 0.3 0.5 0.7 0.8 490 752 14.4 22.1 28 28	LS HS 0 0 0.0 0.0 0 0 585 760 20.2 26.2 27 24	LS HS 700 900 17.9 23.1 33.3 32.7 850 1,220 21.2 30.5 27 24
RETURN AIR- scfm[a]	780 (LI) 1200 ° (HI)[b]	1,250 (LS) 1,600 (HS)[c]	1,550 (LS) 2,300 (HS)[b]	1,400 (LS) 1,850 (HS)[d]
COACH TEMPERATURES - ° F RANGE HEAD ZONE (EQUALIBRIUM) RANGE FOOT ZONE (EQUALIBRIUM) HEAD ZONE-FOOT ZONE DIFFERENTIAL DRIVER AREA -- AVG SUPPLY DRIVER HEAD ZONE (EQUALIBRIUM) DOOR OPENING TEMPERATURE IMPACT	Mean Supply -- 78.3 Mean Return -- 73.8 71 to 81 (fr. to bk.) (Δ = 10) 64 to 74 (fr. to bk.) (Δ = 10) Δ = 6 to 7 83 (medium fan) -75 (medium fan) up to = 45 °[h]	Mean Supply -- 86.8 Mean Return -- 74.3 79 to 70 (fr. to mid. sect.) (Δ = 9) 71 to 48 (fr. to mid. sect.) (Δ = 23) Δ = 11 134 (medium fan) 86 (medium fan) up to 30 °[f]	Mean Supply -- 87.6 Mean Return -- 66.0 79 to 63 (fr. to bk.) (Δ = 16) 67 to 51 (fr. to bk.) (Δ = 16) Δ = 10 to 20 ° 125 (medium fan) Not in text. Only in charts. up to 50[f]	Mean Supply -- 99.3 Mean Return -- 86.6 80 to 86 (fr. to bk.) (Δ = 6) 73 to 87 (fr. to bk.) (Δ = 14) Δ = 4 to 13 Not in text. Only in charts. 81 30 to 40 °

a) Air flow measurements were taken for high an low engine idle conditions. b) Air flow balance within 10 %. c) Air flow balance about 10 %. d) Air flow balance is equal. e) Max impact on driver and seats 5 and 8 with both doors open for 60 seconds. f) Max impacts on driver and seats across from door foot zones, 60 seconds all doors open. g) Max impacts on driver and front passengers foot zones, 60 seconds both doors open. h) Max impacts on driver and front area foot zones, 60 seconds both doors. Rear area less affected. *) Data from charts.

The air supply volumes for the buses ranged from 25.9 to 110 cfm per occupant (using the number of seats plus the driver as the number of occupants). The total air supply under high speed settings ranged from 2,035 to 3,200 standard cubic feet per minute (scfm) when combining the supply air flows from both the passenger area and driver area.

Make up air flows for the passenger area ranged from 0 to 23 cfm per passenger. When the driver MUA was included in the calculation, the range of MUA ranged from 9 to 30.5 cfm per occupant.

The front to back differential temperatures for the passenger area head zone ranged from 8 to 16° F with higher temperatures in the rear for both the NFIL and Nova Bus buses. The two Orion buses had the higher temperatures in the front than the rear of their buses. The driver head zone mean temperatures for a medium fan setting ranged from 75 to 88° F.

Passenger area foot zone temperatures dropped as low as 48° F, and differences in temperatures ranged from 10 to 23° F, with the higher temperatures in the rear of the buses for the NFIL and Nova Bus buses. The two Orion buses had the higher temperatures in the front of their buses.

The head zone to foot zone differential temperatures generally ranged from 4 to 11° F. An exception was observed in the Orion three door bus, where the temperature differential was about 20° F for the seat across from the middle door.

The side to side temperature differentials ranged from 1 to 2° F except for one bus recorded a differential of about 10° F for the front seats.

Measurements of temperature impacts on the passenger and driver areas for various combinations of door openings of 60 seconds were made. With both doors open combined with an outside ambient temperature of 23° F, a maximum temperature drop of 42° F was recorded for the driver and front seat foot zones. With all three doors open, combined with an outside ambient temperature of 15° F, a temperature drop of up to 50° F was recorded for the foot zones of the driver and seats across from the doors. The durations of these temperature drops lasted about 1 to 2 minutes.

IV OVERALL STUDY FINDINGS

From the study of the heating and ventilation of buses several findings were developed. The major overall findings from the urban bus ventilation and climate control tests are discussed in the following paragraphs.

1. Make Up Air (MUA)

Data on the MUA for all of the buses tested are given in Tables 4 and 5. Also, given in tables is the ANSI/ASHRAE 62-1989 Standard for the MUA in transportation vehicles. When considering the MUA flows into the passenger area, three of the low-floor buses are below the ASHRAE Standard of 15 cfm per passenger. As can be seen in Table 4, the range of MUA for these three buses was from 0 to 3.3 cfm per passenger, considerably below the ASHRAE Standard. However, if one combines the MUA flows in to both the passenger and the driver areas, MUA flows attain satisfactory levels (see Table 5), but this requires the driver's ventilation system to be on high speed.

Table 4. Comparisons of the Make Up Air of Test Buses and ASHRAE Standard (Passenger Area Only)

ASHRAE STANDARD and TEST BUS	MAKE UP AIR* Total	Per Occupant	As % of Supply
ANSI/ASHRAE 62-1989	xxxx	15 cfm (min.)	xxxx
GMC CLASSIC -- # 6251	155 cfm	3.9 cfm	13.1 %
NFIL D40S -- # 1915	30 cfm	0.6 cfm	1.2 %
NFIL D40 -- # 9221	380 cfm	7.9 cfm	26.5 %
OBI ORION V -- # 9249	185 cfm	4.0 cfm	16.3 %
NFIL D40 LF -- # 92011	125 cfm	3.3 cfm	8.7 %
OBI ORION VI -- # 1710	17 cfm	0.5 cfm	0.8 %
OBI ORION VI -- # 1711	0 cfm	0 cfm	0 %
NOVA BUS LFS -- # 16-002	900 cfm	23.1 cfm	32.7 %

* For the passenger area heating and ventilation system on high speed setting.

Table 5. Comparisons of the Make Up Air of Test Buses and ASHRAE Standard

(Passenger and Driver Areas)

Error! Bookmark not defined. TEST BUS / ASHRAE STANDARD	MAKE UP AIR*		
	Total	Per Occupant	As % of Supply
ANSI/ASHRAE 62-1989	xxxx	15 cfm (min.)	xxxx
GMC CLASSIC -- # 6251	155 cfm	3.8 cfm	9.5 %
NFIL D40S -- # 1915	490 cfm	9.8 cfm	18.9 %
NFIL D40 -- # 9221	480 cfm	9.8 cfm	22.5 %
OBI ORION V -- # 9249	685 cfm	14.6 cfm	36.4 %
NFIL D40 LF -- # 92011	350 cfm	9.0 cfm	17.2 %
OBI ORION VI -- # 1710	752 cfm	22.1 cfm	28 %
OBI ORION VI -- # 1711	760 cfm	26.2 cfm	24 %
NOVA BUS LFS -- # 16-002	1,220 cfm	30.5 cfm	24 %

* Includes both passenger and driver area heating and ventilation systems. Both systems on high speed conditions.

2. Bus Passenger Area Temperatures

A comparison of the passenger area temperatures of the low-floor buses with the appropriate ASHRAE guidelines is given in Table 6. The ASHRAE Standard 55-1992 gives an acceptable temperature range for winter conditions as 67.7 to 76.3 °F for people in typical winter clothing and primarily engaged in sedentary activity. The Standard also recommends that a vertical air temperature difference within an occupied zone not to exceed 5 °F, measured for 4-inches from the floor to 67 inches from the floor.

As can be seen in Table 6, none of the low-floor buses met the temperature range recommended for winter conditions of the head zone to foot zone temperature differential guideline.

There was a malfunction in the rooftop heating/ventilation system's controller unit for the

Nova Bus during the test run. Therefore, the temperatures recorded within the passenger area of the Nova Bus LSF are questionable.

Table 6. Comparison of Passenger Area Temperatures of the Low-Floor Buses with ASHRAE Standard 55-1992

TEST BUS / ASHRAE STANDARD	PASSENGER AREA TEMPERATURES		
	Head Zone	Foot Zone	Differential
ANSI/ASHRAE 5-1992	61.7 to 76.3° F Winter conditions	61.7 to 76.3 ° F Winter Conditions	5 ° F (maximum)
NFIL D40 S -- # 1904 [a]	94 to 73° F	91 to 75°F	3 to 18 °F
NFIL D40 -- # 9222 [b]	80 to 74°F	79 to 77°F	4 to 7 °F
OBI Orion V -- # 9237 [c]	84 to 75°F	70 to 71°F	5 to 11 °F
NFIL D40 LF -- # 92011 [d]	71 to 81° F	64 to 74 ° F	6 to 7 °F
OBI ORION VI -- # 1710 [e]	70 to 79 ° F	48 to 71 ° F	≈ 11 ° F
OBI ORION VI -- # 1711 [f]	63 to 79 ° F	51 to 67 °F	10 to 20 °F
NOVA BUS LFS -- # 16-002 [g]	80 to 88 ° F	73 to 87 ° F	4 to 13 °F

a) The passenger area thermostat was set on mid-position with low fan speed, the driver area was set on low heat, low fan, and full "fresh air". Avg. differential = 3 °F & 1st seats were 7-18°F.

b) The passenger area thermostat was set on "heat", and the driver area system was set on low heat, low fan, and full "fresh air". Avg. differential = 4 °F & 1st seat row was 7 °F.

c) The passenger area thermostat was set on "heat" and low fan, and the driver area system was set on low fan and 100% outside air. Avg. differential = 5 °F & 1st seat was 11°F.

d) The passenger area thermostat was set at ≈ 70 ° F, the driver area system was set on medium heat and fan, and the auxiliary heat operating.

e) The passenger area thermostat was set at ≈ 73 ° F, and the driver area system was set on medium heat and low fan speed.

f) The passenger area thermostat was set at ≈ 72 ° F, and the driver area system was set on medium heat and low fan speed.

g) The passenger area thermostat was set at ≈ 70 ° F, and the driver area system was set on low fan speed, full foot zone heating, and 25 % heat setting. Avg. differential = 4 °F & 1st seat s was 7-13 °F.

3. Driver Area Temperatures

A comparison of the driver area head zone and foot zone average temperatures are compared with the applicable ASHRAE Standard in Table 7. The settings for the driver heating system controls are the same as are given in the footnotes for Table 6. The driver area temperatures for one of the buses met the ASHRAE guidelines at the test run settings. It appears possible that the driver areas for the other three low-floor buses could be operating within the guidelines of ASHRAE with lower heat and fan settings for the driver heating and ventilation units.

Table 7. Comparison of Driver Area Temperatures With ASHRAE Standard 55-1992

TEST BUS / ASHRAE STANDARD	DRIVER AREA TEMPERATURES Head Zone	Foot Zone	Differential
ANSI/ASHRAE 5-1992	61.7 to 76.3 °F Winter conditions	67.7 to 76.3 °F Winter Conditions	5 °F (maximum)
NFIL D40 S -- # 1904 [a]	≈ 93 °F	≈ 90 °F	≈ 3 °F
NFIL D40 -- #9222 [b]	≈ 72 °F	≈ 86 °F	≈ 14 °F
OBI Orion V -- # 9237 [c]	≈ 84 °F	≈ 67 °F	≈ 17 °F
NFIL D40 LF -- # 92011 [d]	≈ 74 °F	≈ 72 °F	≈ 2 °F
OBI ORION VI -- # 1710 [e]	≈ 85 °F	≈ 88 °F	≈ 3 °F
OBI ORION VI -- # 1711 [f]	≈ 86 °F	≈ 84 °F	≈ 2 °F
NOVA BUS LFS -- # 16-002 [g]	≈ 81 °F	≈ 83 °F	≈ 2 °F

a) Data were obtained from Figures 1 & 2 of Phase 2 Report. Driver fan on high speed.
b) Data were obtained from Figures 3 & 4 of Phase 2 Report. Driver fan on high speed.
c) Data were obtained from Figures 5 & 6 of Phase 2 Report. Driver fan on high speed.
d) Data were obtained from Figures 1 & 2 of Phase 3 Report. Driver setting on medium heat
e) Data were obtained from Figures 1 & 2 of Phase 4 Report.
f) Data were obtained from Figures 5 & 6 of Phase 4 Report.
g) Data were obtained from text of Phase 5 Report.

4. Carbon Dioxide Levels

During Phase 2, measurements of the CO_2 and CO levels were taken during both empty and partial passenger load tests. Table 8 provides information on the observed levels of CO_2 in the test high-floor buses during partial passenger load conditions. The observed levels would likely lead to occasional complaints to frequent complaints, particularly if the ambient air temperature rises. The expected responses from people exposed to various levels of CO_2 are given in Table 9.

A consistent relationship between the MUA flows and the observed CO_2 levels is found when comparing the data given in Tables 4 and 8. This leads to a conjecture that the lower MUA flows of some of the low-floor buses could lead to higher levels of CO_2 in the passenger area. No tests of CO_2 levels were made on the low-floor buses.

Table 8. Observed CO_2 Levels During Partial Passenger Load Tests

BUS IDENTIFICATION	OBSERVATIONS	
	Average Return	Average Supply
NFIL 1991 D 40 S	975 ppm	925 ppm
NFIL 1992 D 40	598 ppm	603 ppm
OBI 1992 Orion V	641 ppm	550 ppm

Source: Phase 2 Report.

Table 9. Expected Comments From People Exposed to Various Levels of CO_2

CARBON DIOXIDE LEVELS (ppm)	COMMENTS
330	Level normally present in the atmosphere
Less than 600	Adequate fresh air
600 to 800	There may be occasional complaints, particularly if the air temperature rises.
800 to 1,000	Complaints are more prevalent
1,000 +	Insufficient make-up air, complaints are general

Source: Indoor Air Quality and CO_2 Levels, Gyan S. Rajhans, Envirotest, Inc.

5. Carbon Monoxide Levels

The CO levels that were observed during both empty and partial passenger load tests of the high-floor buses are given in Table 10. Also, in the table are the Ontario Ministry of Labor regulations concerning CO, and the Federal/Provincial Advisory Committee on Environmental and Health, 1987 recommendations on the acceptable maximum level of CO. These recommendations are for short term exposures such as 1-hour or less, and long term exposures such as 8-hours or longer. The three high-floor buses that were tested for CO easily met all of the regulations and guidelines for CO and CO_2 levels during the tests. These test buses all had marginal fresh air ventilation systems as can be seen by examining the data given in Table 4. None met the ASHRAE Standard for MUA flows.

Table 10. Comparison of Measured CO Levels

BUS IDENTIFICATION	TEST CONDITIONS	OBSERVATIONS
NFIL 1991 D 40 S	No Load Test Partial Load Test	Mean of 2 ppm and Peak of 5 ppm Mean of 2 ppm and Peak of 7 ppm
NFIL 1992 D 40	No Load Test Partial Load Test	Mean of 1 ppm and Peak of 5 ppm Mean of 8 ppm and Peak of 10 ppm
OBI 1992 Orion V	No Load Test Partial Load Test	Not provided. Mean of 7 ppm and Peak of 16 ppm

Source: Phase 2 Report.

Table 11. Recommended Maximum Levels of CO

Regulation/Recommendation	Maximum CO Level
MOL, OHSA O.Reg. 833/90 Time-Weighted Average Exposure (TWAEV)	35 ppm (8-hour exposure)
Proposed Acceptable Short Term Exposure Range (ASTER) [a]	25 ppm (1-hour exposure)
Proposed Acceptable Long Term Exposure Range (ALTER) [a]	11 ppm (8-hour exposure)

a) Federal/Provincial Advisory Committee on Environmental and Health, 1987. Source: Phase 2 Report.

6. Temperature Impacts of Door Openings

Temperature measurements were made for various durations and combinations of door openings. In general, when only the front entrance door is opened, the foot zones of the driver area and driver side passenger seat near the door were most affected. When both front and rear doors were open, the greatest temperature drops were observed in the foot zones of the passenger seats near the doors. Table 12 contains information on the maximum temperature impacts for the driver and passenger areas for various door opening times. In general, the observed temperature drops were higher for the low-floor buses than those observed for the high-floor buses under similar door opening conditions. The duration of the temperature impact is generally related to the length of time that the doors are open. In general, the impact durations ranged from 1 to 2 minutes.

Table 12. Door Opening Impacts on Bus Interior Temperatures

TEST BUS	DOORS OPEN (seconds)	MAXIMUM TEMPERATURE IMPACT* Driver Area (° F drop)	Passenger Area (° F drop)	DURATION OF IMPACT (minutes)
NFIL D40S	20	≈ 32	≈ 10	≈ 1#
NFIL D40	40	≈ 20	≈ 29	≈ 2#
OBI ORION V	90	≈ 30	≈ 17	≈ 2#
NFIL D40 LF	60	≈ 39#	≈ 45#	≈ 2#
OBI ORION VI	60	≈ 30	≈ 30	≈ 2#
OBI ORION VI	60	≈ 45#	≈ 50	≈ 2#
NOVA BUS LFS	60	≈ 30#	≈ 40 #	≈ 2 #

* Maximum temperature drops occurred for all doors open conditions.

\# Duration times were estimated from the graphical data.

More detailed information on the impact of door openings on the passenger areas for the low-floor buses is given in Table 13.

Table 13. Temperature Measurements On Low-Floor Buses During Door Openings*

	NFIL D 40 LF	ORION VI - 2-DOOR		ORION VI - 3-DOOR		NOVABUS LFS	
		FRONT ONLY	ALL DOORS	FRONT ONLY	ALL DOORS	FRONT ONLY	ALL DOORS
MAXIMUM TEMPERATURE DROP TOP OF DOORWAY, Δ in °F	48	30	50	13	35	5 front door 1 rear door	8 front door 14 rear door
MAXIMUM TEMPERATURE DROP BOTTOM OF DOORWAY, Δ in °F	56	45	45	51	70	36 front door 15 rear door	16 front door 70 rear door
MAXIMUM TEMPERATURE DROP PASSENGER AREA, Δ in °F	14[a]	19	30	b	50	42 with both doors open on the seats near rear door	
AMBIENT TEMPERATURES, °F	23	15		15		15	
MEAN RETURN TEMPERATURES, °F	74	74		66		87	

* All door openings were 60-seconds in duration.

a) With both doors open temperature drops to ≈ 35°F were observed in the passenger area.

b) The report text stated that the temperature impact on the passenger area was more severe with all doors open. With all doors open, a passenger area temperature drop of 50°F were observed.

The door openings frequency during the test runs was on the order of one every 15 to 20 minutes. The door openings of a bus in an urban center could be more frequent. Table 14 provides information on door operation of a city bus in San Antonio during the rush hour period.

Table 14. Door Operation of a City Bus (San Antonio, Texas)

	Front Entrance Door	Center Exit Door
Door open, Times per mile (km)	7.5 (4.7)	5.5 (3.4)
Door open, Times per hour	70	44
Door open, Percent of operating time	35	15
Longest time open (seconds)	55	34
Shortest time open (seconds)	3	3
Average time open (seconds)	13.5	12.5

Source: 1995 ASHRAE Applications Handbook, Chapter 8, Surface Transportation.

From Table 14 it can be seen that the door open frequency ranged from 44 to 70 times per hour, or once each minute. Since the recovery time for a 20-second door opening was about one minute, and longer door open times resulted in longer recovery times, it is conceivable that the passenger area temperatures would not fully recover before the next door opening. This could lead to a gradual lowering of the passenger area average temperature.

During the door opening tests under winter conditions for the high-floor buses, it was observed that the cold air would flow in at the base of the doorway and flow out at the top of the doorway. These observations were recorded by video during the smoke tests. It was reported that there was infiltration of cold air at the bottom of the door and exfiltration of air through the top of the door section for the Nova Bus LSF test bus during the door opening tests. The reports did not provide similar information on air flow in the doorways on the other three low-floor test buses during door opening tests. However, the temperature drops given in Table 13 provide some insight on the relative magnitude of the cold air penitration into the passenger areas of the low-floor test buses during the door opening tests.

BIBLIOGRAPHY

Bus Test Reports

CUTA URBAN BUS VENTILATION AND CLIMATE CONTROL STUDY; TEST RESULTS, STRP Report 11A, May 1999

This report contains the following reports:

- Presentation To Cuta's Bus Design And Maintenance Committee, Bus Manufacturers, And Hvac Suppliers, CUTA Fall Conference, Toronto, ON, November 1995

- Phase 1 – Air Flows, Temperatures, Air Patterns, Tests Conducted June 1993, November 1993

- Phase 2 – Cold Weather Tests (Temperatures, Carbon Dioxide, Carbon Monoxide, Relative Humidity), Tests Conducted February-March 1994, April 1995

- Phase 3 – Low Floor Bus (N.F.I.L D40-LF), (Air Flows, Temperatures, Air Patterns), Tests Conducted January 1995, October 1995

- Phase 4 - Low Floor Bus (Orion VI), (Air Flows, Temperatures, Air Patterns), Tests Conducted January-February 1996,

Other Climate Control Tests Conducted by ENVIROTEST Inc.:
(Not Included in Report STRP 11A)

Prepared for Transportation Development Centre, Transport Canda:

- **NovaBUS LFS Urban Bus Ventilation System Testing – Phase 1**, Tests Conducted March 1996, Reference ET 1854.1, May 1996
  (referred to as Phase 5 of the CUTA study in this report)

- **NovaBUS LFS Urban Bus Ventilation System Testing – Phase 2**, Tests Conducted March 1998, Reference ET 1854.2, April 1998

Prepared for Orion Bus Industries:

- **Orion VI Low Floor Bus**, Tests Conducted February 1997, Reference ET 1920.1, March 1997

Other Relevant Documents

- Thermal Environmental Conditions for Human Occupancy, ANSI/ASHRAE 55-1992, ASHRAE Standard.
- Ventilation for Acceptable Indoor Air Quality, ANSI/ASHRAE 62-1989, ASHRAE Standard.
- 1995 ASHRAE Handbook, Applications, Chapter 8, Surface Transportation.
- Modified Houston Pulldown Test, Houston Metro.
- SAE Recommended Practice, (R) Windshield Defrosting Systems Test Procedure - Trucks, Buses, and Multipurpose Vehicles - SAE J381 APR94.
- SAE Recommended Practice, (R) Windshield Defrosting Systems Performance Requirements - Trucks, Buses, and Multipurpose Vehicles - SAE J382 JUN94.
- Procurement Specification for HVAC, Advanced Technology Transit Bus Program, ATTB 300-4050000, May 12, 1995.
- Recommended Instrumentation and Performance Testing for Transit Bus Air Conditioning Systems (Draft), APTA Bus Equipment and Maintenance Committee.
- Air Conditioning of Line-Service Buses, VDV Recommendations 236, 04/96.
- Interior Climate Control (Draft), Excerpt of SEPTA Bus Specifications.
- Baseline Advanced Design Transit Coach Specifications ("White Book"), APTA.

APPENDIX A -- DESCRIPTION OF TEST BUSES

There were a total of eleven buses tested during the program. These buses are identified in Table A-1.

Table A-1. Buses Tested During the Heating and Ventilation Study

NO	TEST PHASE	BUS IDENTIFICATION AND DESCRIPTION						TRANSIT AUTHORITY
		MANUF.*	MODEL NO.	YEAR	NO. OF SEATS	A/C	FLOOR	BUS NUMBER
1	1	NFIL	D40 S	1991	49	YES	HIGH	GO TRANSIT # 1915
2	1	NFIL	D40	1992	48	YES	HIGH	OC TRANSPO # 9221
3	1	OBI	ORION V	1992	46	YES	HIGH	OC TRANSPO # 9249
4	1	GMC	CLASSI C	1987	40	NO	HIGH	TTC # 6251
5	2	NFIL	D40 S	1991	49	YES	HIGH	GO TRANSIT # 1904
6	2	NFIL	D40	1992	48	YES	HIGH	GO TRANSIT # 9222
7	2	OBI	ORION V	1992	46	YES	HIGH	OC TRANSPO # 9237
8	3	NFIL	D40LF	1992	38	YES	LOW	KITCHNER TRANSIT # 9201
9	4	OBI	ORION VI	proto-type	33	YES	LOW	LONDON TRANSIT # 1711
10	4	OBI	ORION VI	proto-type	28	YES	LOW	OC TRANSPO # 1711
11	5	NB	LFS	proto-type	39	YES	LOW	STCUM # 16-002

* NFIL New Flyer Industries Limited
OBI Orion Bus Industries
NB Nova Bus

TEST BUSES NUMBERS 1 AND 5

Passenger Area System

The test buses numbers 1 and 5 are single door suburban coaches equipped with an integrated HVAC system mounted under the floor midsection. Passenger area air is distributed via the full length warm wall plenum along both sides with slots at the window sill level and with grills at the foot zone level. The air return is via aisle grilles along the left side of the aisle only. Outside air supply is via grilles on the left side at mid-section of the bus. The controls are located on the panel below the driver side window, and include two fan speeds, a temperature display, and a temperature control.

Driver Area System

The driver area has an independent AC system mounted above the driver side window with two adjustable louvre nozzles above the window side and two louvre nozzles above the dashboard. The control was mounted on the front dash panel, and had three fan speeds. The heating system has a vent in the driver foot zone, six vents for the windshield defrost, and one vent in the front door footwell. The heating controls were mounted on the dash, and provided for fresh air and recirculation air, temperature selection, and a three speed fan. The outside air supply is via a grille in the front center of the bus located below the floor and behind the bumper.

TEST BUSES NUMBERS 2 AND 6

Passenger Area System

The test buses numbers 2 and 6 are 2-door city transit buses. The passenger heating and ventilation system is mounted under the floor in the midsection of the bus. The air supply distribution system is via full length warm wall plenums along both sides of the bus with air slots at the window sill level and with grilles in the foot zone area. There are also 28 small openings on the left side only in the foot zone only. The air return is via eleven foot well grilles. Outside air supply is via a small grille located mid-section on the left side of the bus

The AC system is roof mounted with air supply distribution via slot above the light strip

along both sides of the bus. Air return is via two ceiling openings in the mid-section of the bus. Outside air supply is via two grilles at the rear of the roof top unit.

The controls for the passenger area air flow and temperature are located on the driver window panel. There is only a single speed control for the heating and ventilation system. The AC system is an automatic dual speed system depending on demand. There is a control to select either a heat, ventilation, or cool mode.

Driver Area System

The driver area heating system has a controllable outlet in the foot zone area, six air vents along the windshield, and a vent in the front doorwell. The controls are located on the dash, and enable the driver to select fresh or recirculated air, temperature, and fan speed. The driver area air return is via louvres at the front center of the bus. The outside air supply is via a grille in the center front of the bus above the bumper.

The AC air for the driver is ducted from the passenger area with two louvres above the driver side window. The driver AC air has a booster system with variable speed control. There is also an AC air duct to provide air via vents at the driver window sill level.

In addition, there are two non-mechanical fresh air vents provided for the driver. One is located on the left side in the upper front area, and the other is located on the left side in the foot zone area. These vents are controllable.

TEST BUSES NUMBERS 3 AND 7

Passenger Area System

The test buses are two door city transit buses, and are served by separate heating/ventilation and air conditioning systems. The heating and ventilation system is mounted under the floor about mid-section of the bus. The air supply is distributed via a full-length warm wall plenum along both sides of the bus with slots at the window sill level plus a series of oval openings along the under side of each plenum in the center section of the bus. There are also grilles on each side of the stepwell in the rear door. Air return is provided by a single "box" duct extending into the mixing chamber under the floor.

The AC for bus number 3 is a roof-mounted Sutrak system with air supply distribution via two slots the length of the bus, one above the light strip and the other above the top of the window. The AC air return is provided by a central ceiling filtered opening. The outside fresh air supply is provided by two grilles at the rear end of the roof-top unit. Bus number 7 is equipped with a Thermo King T-2 AC/HV system mounted on the roof. The air distributions systems are the same as Bus number 3.

The AC controls are mounted on the driver window panel, and include a selector for cool, ventilation, or heat and a two speed fan control.
Driver Area System

Driver Area System

The driver heating system has a vent in the foot zone area, seven vents for the windshield and one vent for the front door stepwell. The three speed fan control is located on the dash. There is no separate driver air return system. The outside fresh air is provided by a grill in the front center of the bus below the floor level, and behind the bumper.

The driver AC air is ducted from the passenger area system to four louvres above the driver side window with a vertical duct to provide AC air at a vent at the window sill level. A two speed AC fan speed control is located on the driver side window panel. There is a controllable non-mechanical fresh air circuit the left side foot zone area.

TEST BUS NUMBER 4

Passenger Area System

Test bus number 4 is a two door city bus with only a heating and ventilation system. The passenger area is served by a heating and ventilation system that is mounted under the floor in the mid-section of the bus with an air supply distribution system via full length warm wall plenum along both sides of the bus. The air flows from the plenum to slots at the window sill level, louvre openings in the foot zone areas, and grilles on both sides of the rear door stepwell. Air return is provided by two "box" ducts extending through the floor into the air mixing compartments. Two outside fresh air grilles are located on the

side of the bus (typically where advertisement panels are hung) are ducted into the mixing compartment. There is a control switch for the fan located on the driver side window panel.

Driver Area System

The driver area heating system has an outlet in the foot zone area and eight diffusers along the windshield. The driver area controls are located on the driver side window panel. The fan control is two speed. An air return grille is located in the right hand side in the front. No separate driver outside air is provided. A heating/ventilation duct from the passenger area feeds three small fixed louvres above the driver side window and a vertical duct provides HV air to an adjustable louvre at the window sill level.

The front door stepwell is served by a booster heater circuit with a separate control (high/low) located on the panel below the driver side window.

Two supplementary non-mechanical fresh air circuits serve the driver area. One provides fresh air to the left hand foot zone area, and the other provides fresh air across the top of the windshield. Both are adjustable by flap/grille controls.

TEST BUS NUMBER 8

Passenger Area System

Test Bus Number 8 is a low-floor two door city bus. The passenger area is served by an integrated heating/ventilation and air conditioning system which is mounted on the roof. The air supply distribution is provided by horizontal and vertical slots along both left and right side bulkheads. The air supply slots were above the windows. Air return is via a central ceiling opening divided into two sections and equipped with filters. The outside fresh air is provided by two intake portals at the rear of the roof-top unit.

An auxiliary heater is located on the door-side under the seat just in front of the rear door. Control for this heater is located in the driver area. The passenger area controls for the HVAC system consist of an automatic "Climate Control" with two fan speeds depending on the heating/cooling demand and engine idle speed. A thermostat control is located in the ceiling air return grille.

Driver Area System

The driver area heating/ventilation air supply is provided by one outlet in the foot zone area, six defrost vents along the windshield, and one outlet in the front door area. Outside fresh air supply is via four grilles at the front underside of the bus.

The controls for the driver system are located on the dash, and consist of a temperature control and a three-speed fan switch.

The driver area AC is ducted from the passenger area system to above the driver side window, and a vertical duct provides air to the window sill level. There are two louvres above the window and one at the window sill level. The driver system has a booster unit with variable speed control.

TEST BUS NUMBER 9

Passenger Area System

Test Bus Number 9 is a prototype two door city transit bus. The passenger area is served by an integrated heating/ventilation and air conditioning system mounted on the roof. The supply air distribution is via horizontal and vertical slots along both right and left side bulkheads. The air return is provided by a central ceiling opening divided into two sections with filters. Outside fresh air is provided by an intake grille located at the roof line at the rear door-side of the bus.

The passenger HVAC control is an automatic "Climate Control" with two fan speeds depending on the heating/cooling demand and engine idle speed. A thermostat control is located at the ceiling air return grille.

Driver Area System

A driver heating system provides supply air to a single foot zone outlet, to seven vents along the windshield, and a vent near the fare collection unit. The driver area controls are located on the dash, and consist of a temperature control and a three-speed fan control.

The driver AC air supply is ducted from the passenger area to above the driver side window with seven vents. The driver AC system has a booster unit with variable speed control.

TEST BUS NUMBER 10

Passenger Area System

Test Bus Number 10 is a prototype three door city transit bus. The passenger area heating/ventilation and air conditioning is provided by an integrated HVAC system mounted on the roof. The air supply distribution is via horizontal and vertical slots along both right and left side bulkheads. There is a supplemental heat system on the driver-side bulkhead involving three window blowers. The air return is via a central ceiling opening with two sections with filters. The outside fresh air supply is provided by an intake grille located at the roof line on the rear of the door side of the bus.

The passenger HVAC system is equipped with an automatic "Climate Control" that has two fan speeds depending on heating/cooling demand and engine idle speed. A thermostat control is located at the ceiling air return grille.

A convection-type radiator is located around the floor perimeter. A fan unit is located under a mid-section seat on the driver side of the bus. A Wabasto engine-coolant heater is used to increase the temperature of the fluid circulated in the radiator. The control of the radiator system is located in the driver area.

Driver Area System

The driver heating/ventilation system has an outlet in the foot zone and seven window defrost vents with louvres. The controls are located on the dash, and include a temperature control and a three-speed fan control. Outside fresh air supply to the driver area is ducted from a filtered intake at the front underside of the bus.

The driver AC air is ducted above the driver side window from the passenger area to

five louvres. A booster system is integrated into the driver AC air, and has a variable speed control.

TEST BUS NUMBER 11

Passenger Area System

Test Bus Number 11 is a prototype low-floor two-door city transit bus. The heating/ventilation and air conditioning system is an integrated system mounted on the roof. The supply air distribution is via above window slots along both right and left sides of the bus. Air return is provided by a central ceiling grille. Outside fresh air supply is via intake ports on the rooftop unit.

Passenger floor area is provided heated forced air convectors from four single speed underseat fans, two on each side. A Wabasto DB WE 2020 engine coolant heater provides a boost capability for the floor area heater. An integrated Mobile Climate Control (MCC) "Climate Control" controls the HVAC system, the floor area heating system, and with make up air a function of return and external ambient temperatures. A passenger area thermostat is located at the ceiling return air grille. The passenger area system has two fan speeds. The system normally operates on the "low" speed setting, but the driver can initiate a "high speed" setting for a 10-minute cycle to facilitate window defrosting.

Driver Area System

The driver area heating system provides supply air to two foot zone outlets, defrost air to 9 vents plus two laterals for the windshield, and a swivel dash louvre. There also is a front door area outlet. The driver area controls are located on the dash, and include a temperature control and a three-speed fan control.

Outside fresh air supply is provided from a filtered intake at the front underside of the bus to the mixing chamber. Return air is drawn from the front dash panel area into the mixing chamber.

A supplemental booster system located within the right dash provides heated air to the

door area and the floor area of seat one on the door side.

The passenger AC air is ducted to two louvres above the driver side window. There is a two-speed booster fan integrated into the driver AC air system.

APPENDIX B -- DESCRIPTION OF TEST INSTRUMENTATION

AIR FLOW AND VELOCITY

The instruments used for air flow measurement were a Sierra Flo-multimeter and an Alnor Balometer. A make-up piece was designed and fabricated to facilitate the accurate measurement of air velocities of the air flowing out of the air supply slots. Both instruments were calibrated and flow comparisons were made so that the instruments could be used interchangeably during the tests. This capability was needed because of the wide range of diffuser/louver sizes and designs that were encountered. The air velocity data obtain by the Sierra Flo-multimeter were recorded and plotted. Total air flow volumes were extrapolated using the measured air velocity data and factoring in the number, design, and dimensions of the air flow openings. For the air flow measurements made with the Alnor Balometer, the total air flows were extrapolated factoring in the number, design, and size of the openings.

AIR TEMPERATURE

Dry bulb temperature (dBT) readings were recorded at a number of points though out the test bus using unshielded thermocouples that were hard-wired to a datalogger A 32-channel Squirrel 1200 Series datalogger was used for the tests. The datalogger was programmed to record data on a 30-second cycle. The thermocouples were placed to obtain head zone and foot zone temperature measurements in the front, middle, and rear of the passenger compartment, and in the driver area. Thermocouples were also placed to obtain temperature measurements at air supply and return openings, and one was used to record the outside ambient temperature.

AIR MOVEMENT

Air movement data were developed using the Sierra Flo-multimeter to measure air velocity and Drager Air Current Tubes to obtain air flow direction data. Air flow pattern profiles were developed for several seat locations (both head zone and foot zone) in the passenger and driver areas. The air movement data was obtained for various settings of the fans, for windows open and closed, and for the bus stationary and moving conditions. A simulated smoke test was also conducted to observe air movement. The air patterns were recorded using an 8mm video camera.

CO AND CO_2

Only during the Phase 2 tests were carbon monoxide (CO) and carbon dioxide (CO_2) measurements made. Carbon monoxide measurements were made using a Draeger Model 190 CO Datalogger and an Analygas Carbon Monoxide Analyzer. The Analygas analyzer was connected to a Squirrel datalogger for recording the data. The CO analyzers were calibrated at the beginning and the end of each field period using a span gas concentration of 58 parts per million (ppm) by volume. Carbon dioxide (CO_2) measurements were recorded at the supply and return air ducts using two Horiba APBA-210 Carbon Dioxide Analyzers connected to the Squirrel dataloggers. The CO_2 analyzers were calibrated immediately prior to and following a test run using 660 and 1637 ppm CO_2 span gas.

RELATIVE HUMIDITY

Relative humidity (RH) measurements were recorded during some mobile runs at the passenger area supply and return air ducts using a factory calibrated Enercorp Model HT-D-420 Humidity Transmitters connected to a Squirrel datalogger.

APPENDIX C – SECOND TEST OF THE NOVA BUS LFS

BACKGROUND

During the first test of the Nova Bus LFS on March 28 and 29, 1996, a malfunction of the control system of the integrated heating and ventilation (HV) system resulted in high temperature measurements being recorded. New tests were conducted on March 25 and 26, 1998 to gather data on make up air (MUA) and passenger compartment temperatures with a properly functioning HV system. In addition, tests were conducted to compare the temperature measurements during a road test and cold room tests. The purpose of these tests was to determine the feasibility of using a cold room test to simulate road test conditions with cold room tests under comparable temperatures. The two buses were said to be the same with respect to their HV systems. The bus for the second test was taken out of regular service from STCUM. The instrumentation and test procedures used in the second test were the same as those used in the first test. The results of the second test are documented in an Envirotest Incorporated report ET 1854.2 entitled "Transport Canada Transportation Centre NovaBus LFS Urban Bus Ventilation System Testing - Phase 2".

A summary of the test results are presented in the following tables. Where appropriate the results of both tests are presented. A brief summary of the road test and cold room comparison tests is also given. There were three test runs during the second test series. A Road Test, a - 8 °C Cold Room Test, and a - 15°C Cold Room Test. The average ambient temperature during the Road Test was - 7°C.

MAKE UP AIR (MUA)

The outside make up air (MUA) was measured under three HV settings. At zero MUA setting, at 50 percent setting, and at 100 percent setting. The driver's ventilation system was off. Data were collected for low and high fan settings for the passenger compartment, and are presented in Table C-1.

Table C-1. Make Up Air Measurements With Passenger Compartment System On

FAN SETTING	MUA HV SETTING	MUA VOLUMES (scfm)
Low Fan	Zero MUA	235
Low Fan	50 % MUA	780
Low Fan	100% MUA	815
High Fan	Zero MUA	465
High Fan	50% MUA	960
High Fan	100 MUA	1140

A comparison of the MUA measurements between the first and second tests are presented in Table C-2. The conditions of High Fan and 50 percent MUA were used in both tests.

Table C-2. Comparison of Test Results for MUA

TEST BUS AND ASHRAE STANDARD	MAKE UP AIR Total	Per Occupant	As % of Supply
ANSI/ASHRAE 62-1989	xxxx	15 cfm (min.)	xxxx
First Test – Bus Number 16-002	900 cfm	23.1 cfm	32.7%
Second Test - Bus Number 17-029	960 cfm	24.6 cfm	34.9*

* The two HV systems were stated to be the same in mechanical design and air flow capacities. Therefore, the same air supply volumes were assumed for the two buses.

It can be seen from Table C-2 that the MUA measurements of the second test were very similar to those measured during the first test. There were no measurements taken in the second test with the Driver's system fan on.

BUS PASSENGER AREA TEMPERATURES

Temperature measurements during the second test were taken using the same instrumentation and sensor locations as were used in the first test. The results of all three tests are presented. Head zone, foot zone, head-to-foot differential, and ambient temperature measurements were recorded. The HV settings were the same for both tests. The test results are given in Table C-3. There were no test data reported for the Driver Area.

Table C-3. Comparison of Passenger Area Equilibrium Temperatures of the Two Tests With the ASHRAE Standard 55-1992

TEST BUS AND ASHRAE STANDARD	PASSENGER AREA EQUILIBRIUM TEMPERATURES Head Zone	Foot Zone	Differential
ASHRAE STANDARD 55-1992	67.7 to 76.3°F Winter Conditions	67.7 to 76.3°F Winter Conditions	5°F (maximum)
First Test - Bus Number 16-002 (avg. ambient temperature –9.4°C)	80 to 88°F	73 to 87°F	4 to 13°F
Second Test - Road Test Bus Number 17-029	62.6 to 67.6°F	56.1 to 68°F	8.1°F*
Second Test - -8°C Test Bus Number 17-029	60.3 to 66.2°F	50.4 to 66.4°F	12.6°F*
Second Test - -15°C Test Bus Number 17-029	55 to 61.2°F	46.6 to 62.8°F	12.6°F*

* Data taken from Charts 4, 7, and 11 of Test Report ET 1854.2.

TEMPERATURE IMPACTS OF DOOR OPENINGS

For the Second Test the data measured for impacts of door openings were taken for the doors being opened for seven seconds only. There were no reported data for a sixty second door opening. Therefore, it is not possible to present direct comparisons between the first and second Tests. The reported impacts of door openings are given in Table C-4.

Table C-4. Impacts of Door Openings

TEST RUN	MAXIMUM TEMPERATURE IMPACT
Road Test	19.8°F
-8°C Cold Room Test	22°F
-15°C Cold Room Test	21.6°F

Smoke tests that were conducted during the Second Test confirmed that the ambient air would flow in the bottom of the doors and interior bus air would flow out of the top of the doors during door openings. The boundary between the in-flow and out-flow air would change depending on the setting of the MUA for the HV system. At higher MUA settings, the boundary would move to lower heights in the doorways.

APPENDIX D - ORION VI WARM WALL PROTOTYPE TEST

A series of tests were conducted on a Orion VI low-floor bus equipped with an engineering prototype warm wall system. The tests were conducted by Envirotest Inc. at the OC Transpo facilities on February 6 and 7, 1997. Air flow and temperature measurements were made using the same type of instrumentation as was used in previous tests. The location of the temperature sensors were in the same locations as in previous tests.

The purpose of the tests was to determine the feasibility and effectiveness of the prototype warm wall system design. In particular, the air flows in the passenger area and, in particular, the air flow across the selected passenger windows and the air distribution in the passenger compartment were measured.

The test bus was taken from the OC Transpo fleet. The test bus was Number 1772, and was a compressed natural gas powered low-floor Orion VI bus. The HVAC system was a roof-mounted ThermoKing with passenger air supply distribution by vent slots in the overhead bulkheads on both the operator and door sides of the bus. The prototype warm wall system was composed of window and floor level forced air vents in seat rows one through eight with six variable speed under seat blowers (three per side), two dual-speed under seat blowers in the wheelchair location areas (seat two on both sides), and rear seat under seat blower with foot level vents directed at the center aisle and rear door well. The heat source for the prototype warm wall system was a "Wabasto" 104,000 BTU system that provided recirculated heated air. The HVAC return air grill was in the center aisle in the rear wheel housing area. The make up air (MUA) intake was located above the rear door. The operator heating, ventilation, and defroster system was similar to the previously tested Orion VI low-floor buses.

Two road tests runs were made. One with the passenger compartment thermostat set at 70°F with a low fan setting. The operator area system was set on medium heat and low fan. For the second run the initial conditions were the same, however, the warm wall system was switched to high fan after eight minutes, the operator area fan switched to high fan after 13 minutes, the passenger area thermostat set to 78°F after 19 minutes, and the operator area fan and heat to maximum after 23 minutes. The doors were opened for sixty seconds beginning at 3 minutes and 36 minutes in the second run.

Air flows were measured on windows three and five on both the operator and door sides of the bus. The graphical data shows air flows extending to 75% of window height, with strong air flows in the lower third of the windows. Also, shown graphically the air flows were upward on the windows in the warm wall areas. As a proof of concept, the test data indicate the feasibility of the warm wall concept design. There were wide ranges of air flow velocities (20 to 140 fpm) measured in the head zone area of the bus. Also, there were wide ranges of temperatures (77°F to 109°F) measured in foot zone of the bus. These wide ranges are attributed to the stage of development of the warm wall system design at the time of the tests, and with further development would undoubtedly improve.

LOW-FLOOR BUS CLIMATE CONTROL SYSTEM (CCS)

PART A: PERFORMANCE SPECIFICATIONS GUIDELINES

PART B: TEST PROCEDURES

MAY 1999

Prepared by:

Rolland King

on behalf of the:

BUS DESIGN AND MAINTENANCE COMMITTEE
CANADIAN URBAN TRANSIT ASSOCIATION

LOW-FLOOR BUS CLIMATE CONTROL SYSTEM

TABLE OF CONTENTS

A. PERFORMANCE SPECIFICATIONS GUIDELINES

		PAGE NUMBER
I.	INTRODUCTION	1
II.	STANDARDS AND REGULATIONS	2
III.	CLIMATE CONTROL SYSTEM REQUIREMENTS	3
	III.1 General Requirements	3
	III.2 Capacity and Performance	3
	III.2.a Heating Requirements	3
	III.2.b Ventilation Requirements	4
	III.2.c Cooling Requirements (Optional)	4
	III.3 Design Operating Profile	5
	III.4 Air Distribution	6
	III.5 Air Intakes	7
	III.6 Passenger Compartment Temperature Requirements	8
	III.7 Operator Compartment Requirements	8
	III.7.a Operator Heating, Ventilation, and Defroster Requirements	8
	III.7.b Operator Cooling Requirements (Optional)	10
	III.8 Controls for the Climate Control System	10
	III.8.a Passenger Compartment	10
	III.8.b Operator's Compartment	11
	III.8.c Other Control Requirements	11
	III.9 Servicing and Maintenance	12
	III.10 Noise Levels	14
IV.	GLOSSARY OF TERMS AND ABBREVIATIONS	15
V.	DEFINITIONS	15

B. TEST PROCEDURES

		Page Number
I.	INTRODUCTION	17
II.	TEST OBJECTIVES	17
III.	TEST DESCRIPTIONS	17
III.a	Heating Capacity Test	21
III.b	Ventilation Mode Test	24
III.c	Air Distribution Test	25
III.d	Defroster Test	26
III.e	Passenger Windows Defogging Test	27
III.f	CCS Noise Level Test	29
III.g	Cooling Test	30

A. LOW-FLOOR BUS CLIMATE CONTROL SYSTEM PERFORMANCE SPECIFICATIONS GUIDELINES

I. INTRODUCTION

The purpose of these specifications is to define the performance requirements for the Climate Control System (CCS) for low-floor transit buses. The CCS includes all of the equipment required to provide heating and ventilation (and optional cooling) of the bus, and the control of these functions for the comfort of all occupants.

The bus shall be equipped with an integrated CCS that automatically adjusts the amount of heated, cooled, or make up air (MUA) entering and exiting the interior of the bus. The system shall provide sufficient volumes of heated, cooled, or make up air uniformly distributed and at velocities and locations that meet commonly accepted physiological needs for a comfortable healthy environment.

II. STANDARDS AND REGULATIONS

1) ASHRAE Standard 55-1992, Thermal Environment Conditions for Human Occupancy.

2) ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality.

3) ASHRAE Standard 52.1-1992, Gravimetric and Dust-Spot Procedures for Testing Air -Cleaning Devices Used in General Ventilation for Removing Particulate Matter.

4) SAE Recommended Practice J 382, Windshield Defrosting Systems Performance Guidelines, Trucks, Buses, and Multi-Purpose Vehicles, June 1994.

5) SAE Recommended Practice J 381, (R) Windshield Defrosting Systems Test Procedure – Trucks, Buses, and Multi-Purpose Vehicles, April 1994.

6) Standard Bus Procurement Guidelines, Technical Specifications, 35 and 40-foot Low Floor Diesel, American Public Transportation Association, May 2000.

III. CLIMATE CONTROL SYSTEM REQUIREMENTS

III.1 General Requirements

a) The CCS shall incorporate a forced air system utilizing fans and ducts to provide a positive pressure within the bus body while the bus is in service.

b) The volume, velocity, and direction of the air flow shall be sufficient to prevent fogging or frosting of the entire surface of all of the windows under conditions of high humidity and extreme cold with a Full Standee Load. The heating system should be a hot water type with "warm wall" forced air circulation. The system should incorporated air supply vents immediately below and directed at the passenger side windows.

Alternate air and heat sources will be considered if it can be demonstrated to offer similar performance as required by the specifications.

c) For quick warm up or cool down of the bus interior during start up operation only, the use of 100 percent re-circulated air will be allowed. The time allowed shall be less than 20 minutes from engine start up..

III.2 CAPACITY AND PERFORMANCE

The CCS shall be capable of the requirements given below.

III.2.a Heating Requirements

The capacity of the heating portion of the CCS shall be suitable for all winter conditions in all

major urbanized areas of Canada. It shall be capable of maintaining an average minimum temperature of 15°C (59°F) inside the bus when operating at -40°C (-40°F) ambient temperature with no passengers on board and the doors closed. The interior climate of the bus shall be maintained at this level without solar gain (bus testing shall be done at night or in cold room, and while the bus is running the Design Operating Profile defined in Section III.3).

III.2.b Ventilation Requirements

The ventilation (Vent) mode shall be designed to provide forced air ventilation from the heater and/or cooling systems with no heating or cooling. When operating in the ventilation mode, 100 percent of the air introduced into the bus shall be MUA. The ventilation mode shall provide MUA uniformly to the bus interior at a minimum flow rate of 0.4 m^3/m (15 cfm) per occupant, for occupant loads up to a Full Standee Load.

III.2.c Cooling Requirements (Optional)

With the bus running at the Design Operating Profile and carrying a Full Standee Load, the CCS shall maintain a passenger compartment temperature within a range of 18° and 27°C (65° and 80°F), while controlling the relative humidity to a value of 50 percent or less. The cooling requirements shall be based on each passenger generating 270 Btu per hour of sensible heat and 270 Btu per hour of latent heat. The system shall maintain these conditions while subjected to any outside ambient temperatures up to 35°C (95°F), and at any ambient relative humidity levels between 5 and 50 percent. When the bus is operated in outside ambient temperatures of 35°to 46°C (95°to 115°F), the interior temperature of the bus shall be permitted to rise 1°F (.55°C) for each degree Fahrenheit of exterior temperature in excess of 95°F (35°C).

The cooling portion of the CCS shall be capable of reducing the passenger compartment temperature from 43°to 32°C (110°to 90°F) in less than 20 minutes after engine start up. Engine temperature shall be within the normal operating range at the time of start-up of the cool-down test and the engine speed shall be limited to fast idle that may be activated by an operator-

controlled device. During the cool-down period the refrigerant pressure shall not exceed safe high-side pressures, and the condenser discharge air temperature, measured 150mm (6 inches) from the surface of the coil, shall be less than 25°C (45°F) above the condenser inlet air temperature. The bus shall be parked in direct sunlight with ambient temperature at 38°C (100°F), and humidity shall be less than 20 percent. There shall be no passengers on board and the doors shall be closed.

Manually controlled shutoff valves in the refrigerant lines shall allow isolation of the compressor, receiver, and for filter dryer service. The condenser shall be located to efficiently transfer heat to the atmosphere, and shall not ingest air warmed above ambient temperature by the bus mechanical equipment, or to discharge air into any other system of the bus. The location of the condenser shall preclude its obstruction by wheel splash, road dirt or debris.

III.3. Design Operating Profile

The CCS shall meet the requirements listed in this specification under all of conditions of the bus operating cycle defined herein. The Design Operating Profile consists of the following phases repeated in the sequence given in Table 1.

1) A Central Business District (CBD) Phase of 3.2 kilometers (two miles) with two stops per kilometer (seven stops per mile) and a top speed of 32 kmph (20 mph).

2) An Arterial Phase of 3.2 kilometers (two miles) with one stop per kilometer (two stops per mile) and a top speed of 64 kmph (40 mph).

3) A Commuter Phase of 6.4 kilometers (four miles) with one stop and a maximum speed of 88 kmph (55 mph).

4) An Idle Phase of five minutes.

Table 1. Design Operating Profile Sequence

Phase	Kilometers (Miles)	Top Speed in kmph (mph)	Dwell Time in seconds	Approximate Phase Time in minutes/seconds	Total Stops
CBD	3.2 (2)	32 (20)	7	9/20	14
IDLE	-	-	-	5/0	-
Arterial	3.2 (2)	64 (40)	7	4/30	4
CBD	3.2 (2)	32 (20)	7	9/20	14
Arterial	3.2 (2)	64 (40)	7	4/30	4
CBD	3.2 (2)	32 (20)	7	9/20	14
Commuter	6.2 (4)	88 (55)	20	5/10	1
Totals	22.5 (14)			47/10	51

Source: Reference 6, Section 5.1.2(20).

III.4. Air Distribution

a) Air shall be distributed throughout the bus body in such a manner as to minimize temperature and humidity variations throughout the bus interior. The supply air system shall be capable of providing at least 51 m^3/m (1,800 cfm) to the bus interior. The supply air flow shall contain at least 0.4 m^3/m (15 cfm) per occupant of fresh make up air as a minimum during the heating and cooling modes, except for the extreme cold ambient temperatures. For ambient temperatures in the range of -40 to -20°C (-40 to-4°F), the fresh make up air may be reduced to a minimum of 0.2 m^3/m (7.5 cfm) per occupant. The occupant load is defined as full standee load. As a minimum 6.5m^3/m 230 cfm of the total air supply volume shall be directed at the floor vents evenly distributed throughout the bus.

b) The heating system shall incorporate supply air vents to all doorway areas to prevent buildup

of ice, snow, or slush in these areas. Air shall be ducted through focused directional vents at a minimum rate of 0.4 m^3/m (15 cfm) to each of the doorway areas.

c) Air supply ducts above and/or below the passenger windows shall be provided and supply air to within 150mm (6 inches) of both ends of the passenger seating area.

d) The CCS shall be capable of fully defogging all passenger and operator windows in 30 minutes in an empty coach from a cold start. Once the coach is in operation, carrying a Full Standee Load and cycling the doors, the system shall be capable of maintaining a minimum of 50% defog on all passenger windows and 100% defog on the operator's window, windshield, and front door .

e) To allow the Operator to monitor passenger compartment conditions and to provide comfort to the Operator, there shall be air flow to the operator's compartment from the passenger compartment heating, ventilation, and optional cooling system. This air flow shall have direct ducting and be controllable by the Operator.

III.5. Air Intakes

a) Outside openings for air intake shall be located to ensure cleanliness of air entering the system, particularly with respect to road spray/dirt and exhaust emissions from the coach and adjacent traffic. All intake openings shall be baffled to minimize entry of snow, sleet, or water and shall allow drainage of water. All fresh make up air shall be taken from an area which precludes ingestion of its own vehicle exhaust.

b) All outside air and re-circulated air entering the passenger compartment shall be filtered. The filter shall meet at a minimum the ASHRAE Standard 52.1-1992 testing requirements for a 5 percent or better atmospheric dust spot efficiency, a 50 percent weight arrestance, and a minimum dust holding capacity of 120 grams per 28 m^3/m (1,000 cfm) cell.

These filters may be the throw away type or the cleanable type. Air filters shall be readily accessible for servicing. The filter type and installation require approval by the Transit Authority.

c) Moisture drains from air intake openings shall be located so that they will not be subject to clogging from road dirt.

III.6. Passenger Compartment Temperature Requirements

a) The CCS shall be designed to thermostatically maintain the passenger compartment temperatures within the ranges of 15° to 24°C (60° to 75°F) for winter conditions. For cooling requirements, see paragraph III.2.b (Optional). The CCS shall be capable of providing these temperatures with the bus running the Design Operating Profile.

b) Vertical air temperature difference within the passenger compartment shall not exceed 3°C (5°F), measured at 102 mm (4 inches) from the floor to 1702 mm (67 inches) from the floor for any and all combinations of locations within the bus, under steady conditions.

c) The longitudinal/ lateral air temperature differences within the passenger compartment shall not exceed 3°C (5°F) for any and all combinations of locations within the bus, under steady conditions.

III.7. Operator Compartment Requirements

III.7.a Operator Heating, Ventilation, and Defroster Requirements

A separate heating, ventilation, and defroster system for the operator's area shall be provided, and

be controlled by the Operator. The system shall meet the following requirements.

1) The heater and defroster system shall provide heating for the Operator and heated air to completely defrost and defog the windshield, operator's side window, and the front door glasses in all operating conditions. Fan(s) shall be able to draw air from the bus body interior and/or ambient exterior air through a control device and pass it through the heater core to the defroster system, and over the operator's feet. A minimum capacity of 2.8 m^3 per minute (100cfm) shall be provided. The Operator shall have complete control of the heat and fresh air flow for their area.

2) The defroster supply outlets shall be located at the lower edge of the windshield. These outlets shall be unbreakable and shall be free of sharp edges that can catch cleaning cloths during normal daily cleaning. The system shall be such that foreign objects such as coins or tickets cannot fall into the defroster air outlets. Adjustable ball vents shall be provided at the left of the operator's position to allow direction of air onto the side windows. Two additional ball vents shall be located on the vertical front dash panel adjacent to the front door to allow direction of air onto the door windows and/or entrance area.

3) Heater filters shall be directly in front of the core to filter "all air" forced through the core. Filters positioned at the air inlet to the heater box are not acceptable. All filters shall be cleanable or disposable, and easily accessible for servicing or replacement. Filters should not be visible to the Operator or passengers.

4) An operator's ventilation system shall be provided to ensure Operator comfort, and be capable of providing fresh make up air in both the foot and head areas. The vents shall be controllable by the Operator from the normal driving position. Decals shall be provided indicating "operating instructions", and "open" and "closed" positions as well. When closed the upper vent shall be sealed so as to prevent the migration of water or air into the bus.

5) The CCS shall deliver at least 2.8 m^3/m (100 cfm) of air to the operator's area when operating in the ventilation and optional cooling modes. Adjustable nozzles at both upper and lower outlets

shall permit variable distribution or shutdown of the air flow.

6) The windshield defrosting system shall meet the requirements of SAE Recommended Practice J382, Windshield Defrosting Systems Performance Requirements.

III.7.b Operator Cooling Requirements (Optional)

1) The CCS shall be designed to maintain the operator's compartment temperatures within the range given in III.2.b for the passenger compartment.

III.8. Controls for the Climate Control System

III.8.a Passenger Compartment

The controls for the passenger compartment heating, ventilation, and optional cooling systems shall be integrated and meet the following requirements.

1) The passenger compartment heating, ventilation, or optional cooling mode shall be manually selected by the Operator. Once selected, the system shall operate automatically.

2) A single switch shall be used for mode selection. The switch shall be labeled "Climate Control" with positions for "Off", "Vent", and "Heat" or "Off", "Cool", "Vent", and "Heat" if the cooling option is selected.

3) All controls for the CCS shall be grouped in a blue color coded area of the operator's side control panel and shall be easily accessible to the Operator. Any warning information shall be clearly shown.

4) The passenger compartment temperature shall have an adjustable range of 15° to 24°C (59° to 75°F). The thermostat shall be enclosed in a tamper-proof enclosure located in the return air stream and easily accessed for servicing and adjustment.

III.8.b Operator's Compartment

The controls for the operator's compartment heating, ventilation, and defroster, and optional cooling systems shall be integrated and shall meet the following requirements.

1) The system fan(s) shall be controlled by a separate switch which has an "Off" position and at least two (2) positions for speed control. If recommended by the manufacturer and approved by the Transit Authority, a fan speed switch may be located near the main system function switch. All switches shall preclude the possibility of clothing becoming entangled and shields shall be provided, if required. Auxiliary dash-mounted fans should not be required.

2) A manually operated control valve shall control the coolant flow through the heater core. If a cable operated manual control valve is used, the cable length shall be kept to a minimum to reduce cable seizing. Heater water control valves shall be "positive" type, close or open. The method of operating remote valves requires approval by the Transit Authority.

III.8.c Other Control Requirements

1) All pumps, compressors, and fans shall operate only when the engine is running and the alternator is charging.

2) Failure of the bus electrical charging system shall result in the automatic shutdown of the Climate Control System.

3) If the cooling option is selected it shall be possible to switch to the cooling mode while the bus is in motion. Also, the system shall switch automatically from the "Cooling" to the "Vent" mode if the refrigerant compressor or condenser fan fails.

III.9. Servicing and Maintenance

a) All blower motor shafts shall be coated with heavy duty rust inhibitor (e.g. LPS 3), or approved equal, before installation of the blower fan.

b) Hinges and latches, including the attachment rivets of the heating compartment doors shall be non-corroding.

c) Wherever flexible connections are used to join pipes carrying fluids, they shall be readily accessible for inspection, tightening, and replacement. The gap between pipes shall be adequate to permit replacement of connections without moving the pipes. All pipes and hoses shall be raised at least 25 mm (1 inch) off the floor with non-metallic blocks or in an approved manner. All pipes running outside the heated portions of the bus body shall be wrapped with a suitable insulating material. Use of flexible hoses shall be kept to a minimum. Where necessary, only premium quality hoses shall be used along with premium quality constant torque hose clamps.

d) If the individual heater units are located under passenger seats, they should not be mounted on the floor. This type of heater shall be mounted in such a manner as to allow for easy cleaning of the floor, and for easy removal of the heater as a unit for repairs. The mounting system shall prevent the transmission of vibration to the seats and bus body. If the design precludes suspended mounting of the heater units under the seats, the outer casing and all components contacting the floor shall be of a corrosion proof material.

e) The heater main distribution ducts, if within 150 mm (6 inches) of the floor level, shall be of

smooth stainless steel. The ducts shall be sufficiently sturdy to resist damage by passengers. These ducts shall be constructed to exclude water entry into the duct or shall permit complete drainage when the interior of the bus is washed by means of a water hose.

f) The heating system shall be a self-bleeding type and shall have adequate facilities in the coolant section to permit simple and rapid draining.

g) The heating system shall have readily accessible coolant circulation shut-off valves for the entire passenger heating system. The location of the valves shall be approved by the Transit Authority.

h) The heater core for the operator's compartment shall be removable from the bus through access panels and without the removal or deformation of a panel, if located under the dashboard. The defroster core should have isolation valves at both the inlet and outlet of the core for servicing and replacement.

i) For servicing purposes, the engine cooling system should be able to be run for servicing purposes below the minimum specified ambient temperature.

j) The CCS shall be equipped with blower motors that are completely maintenance free for a minimum of 40,000 hours. The motor shall be readily accessible for inspection and for removal and replacement of the motor and assembly as a unit. This motor shall be individually protected by a manual reset circuit breaker.

k) (Optional) The coolant booster pump should be maintenance free for a period of 40,000 hours, and shall be rebuildable using components readily available in North America.

III.10. Noise Levels

a) The CCS design shall take into account sources of noise generation such as high air velocity, fans, motors, and vibration. Specific measures shall be taken to eliminate sources of noise and/or reduce transmission of vibration both airborne and solid borne. The installation of the water flow/control valve shall ensure that "water hammer" and resulting noise does not occur from sudden operation of the valve. The practices given in the latest edition of ***Industrial Noise Control*** by McGraw-Hill are recommended as a guideline.

The noise level at 1200 mm (48 inches), the approximate ear level of seated occupants, shall not be increased over baseline noise levels by more than an overall "A" weighted sound pressure level of 2dB(A) by the CCS operating in any mode(heating, ventilation, or cooling) at maximum settings, with the bus stationary, the engine running at both idle and maximum throttle, no passengers, and all doors, vents, and windows closed over a baseline noise level. The baseline noise levels shall be measured with the CCS off, with the bus stationary, the engine running at both idle and maximum throttle, with no passengers, and all doors, vents, and windows closed.

IV. GLOSSARY OF TERMS AND ABBREVIATIONS

APTA – American Public Transportation Association

ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Btu – British thermal units

CCS – Climate Control System

cfm – cubic feet per minute

°C – degrees Celsius

°F – degrees Fahrenheit

in. – inches

kmph - kilometers per hour

mm – millimeters

m^2 - square meters

m^3 - cubic meters

m^3/m - cubic meters per minute

mph – miles per hour

SAE – Society of Automotive Engineers, Inc.

V. DEFINITIONS

Full Standee Load	An adult passenger seated in each seat plus an adult standee for each available 0.3 m^2 (3 ft^2) of open floor area.
Seated Load	An adult passenger seated in each seat.

B. LOW-FLOOR BUS CLIMATE CONTROL SYSTEM TEST PROCEDURES

I. INTRODUCTION

A matrix of verification methods for the requirements defined in the CCS Performance Specifications is given in Table 1. Requirements that need measurement of air flows, temperatures, or noise level will be verified by the following tests. All other requirements of the CCS will be verified by inspection and/or functional test (e.g. test of interlock).

II. TEST OBJECTIVES

The objectives of these tests are to measure and record the performance of the Climate Control System (CCS) under specified conditions.

III. TEST DESCRIPTIONS

The performance of the CCS with respect to temperatures, temperature distributions, air flows, and noise levels in both the passenger compartment and the operator compartment will be measured as defined in the following tests.

TABLE 1. MATRIX OF REQUIREMENTS AND VERIFICATION METHODS

SPEC NO.	DESCRIPTION OF REQUIREMENT	VERIFICATION METHOD
III.1.a	CCS provides a positive pressure in bus	Functional test - measure during Heating Capacity and Air Distribution Tests
III.1.b	Prevent fogging of windows and warm wall option	Inspection and Measure during Passenger Windows Defogging Test
III.1.c	Start up operation of 100 percent re-circulated air	Inspection and Measure during Heating Capacity Test (timed temperature measurements)
III.2.a	Heating capacity of CCS, extreme cold conditions	Measure during Heating Capacity Test (extreme cold conditions no solar heating -- temperature measurements)
III.2.b	Ventilation requirements	Measure during Ventilation Tests (air flow measurements)
III.2.c	Cooling capacity of CCS (Optional)	Measure during Cooling Test (extreme hot conditions, full sun) (temperature measurements – Houston Pull Down Test)
III.4.a	Supply air flow, MUA, and floor air supply	Measure during Air Distribution Tests (air flow measurements)
III.4.b	Air flow rate of doorway vents	Inspection and measure during Air Distribution Tests (air flow measurements)
III.4.c	Air outlet at ends of passenger compartment	Inspection and direct measurement of ducts
III.4.d	Capability of defogging windows	Measure during Passenger Windows Defogging Test

SPEC NO.	DESCRIPTION OF REQUIREMENT	VERIFICATION METHOD
III.4.e	Supply air flow from passenger compartment to the operator's compartment and outlet in operator's area	Inspection
III.5.a	Location of outside air intakes	Inspection
III.5.b	Air intake filter location and type	Inspection
III.5.c	Air intake moisture drains location	Inspection
III.6.a	Passenger compartment temperature requirements	Inspection of control range and measure during Heating Capacity Test and optional Cooling Test (temperature measurements)
III.6.b	Vertical temperature differentials	Measure during Heating Capacity Test (temperature measurements)
III.6.c	Longitudinal and lateral temperature differentials	Measure during Heating Capacity Test (temperature measurements)
III.7.a	Operator`s compartment - heating, ventilation, and defroster - design approach, location of vents, effectiveness, and air flow capacity	Inspection and Measure during Heating Capacity , Ventilation, and Cooling (optional) Tests (temperature and air flow measurements) - - Defroster Test - uses the SAE Recommended Practice J381
III.7.b	Operator`s compartment cooling (Optional)	Measure during Cooling Test (Optional)
III.8.a.1)	Passenger compartment controls - manual & automatic	Inspection and functional test of CCS control
III.8.a.2)	Passenger compartment controls - switch type	Inspection
III.8.a.3)	Passenger compartment controls -location and accessibility - - warnings clearly shown	Inspection
III.8.a.4)	Passenger compartment thermostat	Inspection

SPEC NO.	DESCRIPTION OF REQUIREMENT	VERIFICATION METHOD
III.8.b.1)	Operator's compartment control - fan switch	Inspection
III.8.b.2)	Operator's compartment - coolant valve	Inspection
III.8.c.1)	Interlock control - pumps, compressors, and fans	Inspection and functional tests of interlock
III.8.c.2)	Interlock control - failure of electrical charging system	Inspection and functional test of interlock
III.8.c.3)	Cooling mode interlocks (Optional)	Inspection and functional tests of interlocks
III.9.a	Anti seizing compound on motor shafts	Inspection
III.9.b	Non-corroding hinges and latches	Inspection
III.9.c	Piping requirements	Inspection
III.9.d	Under passenger seat heater location and mounting	Inspection
III.9.e	Air flow distribution ducts - location and materials	Inspection and direct measurement of ducts
III.9.f	Heating system type - self bleeding	Inspection and functional test
III.9.g	Heating system shut off valve	Inspection
III.9.h	Heater core removal	Inspection
III.9.i	Cooling system operation for servicing	Inspection
III.9.j	Fan motor type and accessibility	Inspection
III.10.a	Noise levels	Measure during CCS Noise Level Differential Test

III.a Heating Capacity Test

The purpose of this test is to measure the heating capacity performance of the CCS.

1) Test Conditions

The test conditions are:

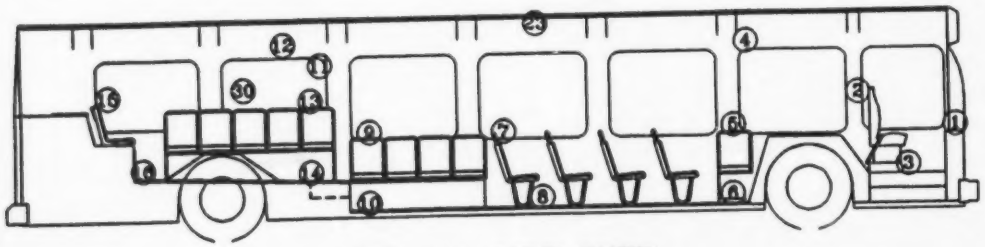
- Exterior ambient temperature at -40 °C (-40 °F),
- Interior bus temperature at 0 °C (32 °F) or colder at start of test,
- Windows, doors, and hatches closed,
- No passengers,
- At the start of the test, engine temperature at normal operating temperature, and
- Passenger and Operator systems at maximum heating settings.

2) Measurements

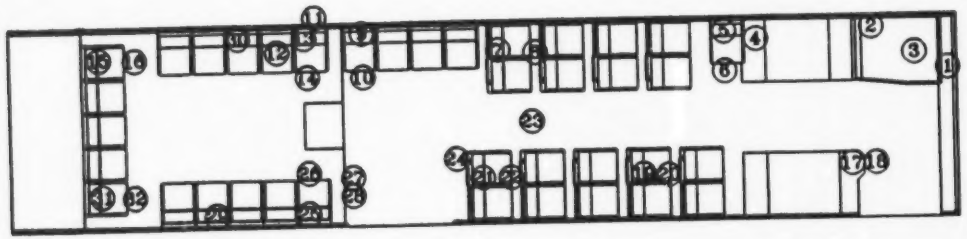
a) Dry bulb temperature measurements shall be made at the following general locations as a minimum (See Drawing 1 - Thermocouple Measurement Locations on Low-Floor Bus):

- At the Operator's seat,
- At the first passenger seats in front of bus on both sides,
- At seats approximately one half the distance between the doors,
- At seats adjacent to and across from a door,
- At seats approximately one half the distance between the center door and rear of the bus,
- At seats in the last row of the bus, and
- Ambient air outside of the bus.

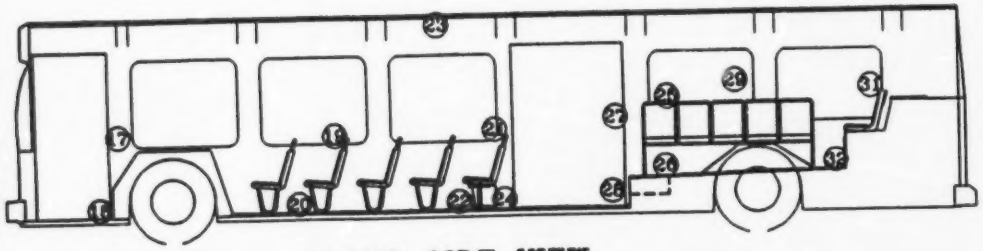
DRAWING 1



DRIVER'S SIDE VIEW



TOP VIEW



DOOR SIDE VIEW

THERMOCOUPLE POSITIONS

1. OPERATOR'S WINDSHIELD DEFROSTER SUPPLY
2. OPERATOR'S SEAT POSITION - HEAD LEVEL
3. OPERATOR'S SEAT POSITION - FOOT LEVEL
4. L.S. FRONT - OVERHEAED HEATING VENT SUPPLY
5. L.S. #1 AISLE FACING SEAT POSITION - HEAD LEVEL
6. L.S. #1 AISLE FACING SEAT POSITION - FOOT LEVEL
7. L.S. 4TH ROW FORWARD FACING SEAT POSITION - HEAD LEVEL
8. L.S. 4TH ROW FORWARD FACING SEAT POSITION - FOOT LEVEL
9. L.S. #5 AISLE FACING SEAT POSITION - HEAD LEVEL
10. L.S. #5 AISLE FACING SEAT POSITION - FOOT LEVEL
11. OUTSIDE AMBIENT
12. L.S. REAR - OVERHEAD HEATING VENT SUPPLY
13. L.S. #6 AISLE FACING SEAT POSITION - HEAD LEVEL
14. L.S. #6 AISLE FACING SEAT POSITION - FOOT LEVEL
15. L.S. REAR BENCH SEAT POSITION - HEAD LEVEL
16. L.S. REAR BENCH SEAT POSITION - FOOT LEVEL
17. FRONT ENTRANCE DOOR AREA - TOP
18. FRONT ENTRANCE DOOR AREA - BOTTOM
19. R.S. 2ND ROW FORWARD FACING SEAT POSITION - HEAD LEVEL
20. R.S. 2ND ROW FORWARD FACING SEAT POSITION - FOOT LEVEL
21. R.S. 5TH ROW FORWARD FACING SEAT POSITION - HEAD LEVEL
22. R.S. 5TH ROW FORWARD FACING SEAT POSITION - FOOT LEVEL
23. COLD AIR RETURN DUCT - CEILING LEVEL
24. R.S. FLOOR LEVEL HEATING SUPPLY - AUXILIARY HEATER
25. R.S. #1 AISLE FACING SEAT POSITION - HEAD LEVEL
26. R.S. #1 AISLE FACING SEAT POSITION - FOOT LEVEL
27. REAR EXIT DOOR AREA - TOP
28. REAR EXIT DOOR AREA - BOTTOM
29. R.S. #4 WINDOW (1" FROM GLASS)
30. L.S. #5 WINDOW (1" FROM GLASS)
31. R.S REAR BENCH SEAT POSITION - HEAD LEVEL
32. R.S REAR BENCH SEAT POSITION - FOOT LEVEL

		OC TRANSIT	
		CUTA VENTILATION STUDY - PHASE III COLD TEMPERATURE TESTING-LOW FLOOR BUS OCTRANSPO UNIT #92011 - NFI D40-LF	
DRAWN N.F.L.L.	DATE		
MODIFIED PAUL A. DAVIDSON	02/01/93	SIZE B / FSCM NO. / DWG NO. 0CP3-92011-1	REV
DESIGN		SCALE	SHEET 1 OF 1

o -- Suggested sensor locations

	Number of sensors:
Operator compartment	3
Passenger compartment (except last row)	24
Passenger compartment, last row	4
Ambient temperature	1
Total	32

For locations with forward facing (or rearward facing) seats, temperature measurements shall be made at three positions, two at passenger seats adjacent to a window on both sides of the bus, and one at the center of the aisle of the bus. Measurement positions in the last row of the bus are reduced to two, at two sides, or at side and center, if three or fewer seats are provided in this row.

For locations with aisle facing seats, temperature measurement shall be made at three positions, two at the passenger seats on both sides of the bus, and one at the center of the aisle of the bus.

For a combination row of forward facing and aisle facing seats, temperature measurements shall be made at three positions, one each at the passenger seats adjacent to a window, and one at the center of the aisle of the bus.

At all of the above positions, except for the operator position, measurements shall be made at 100 mm (4 inches) from the floor and at 1700 mm (67 inches) from the floor. For the operator position, the measurements shall be made at the head and foot zone levels.

All temperatures shall be recorded simultaneously.

3) Requirements

While the bus is running the Design Operating Profile defined in Section III.3 of the CCS Performance Specifications Guidelines, the temperatures measured at any occupant location shall meet the requirements given in Sections III.2.a and III.6 of these specifications. The time measurement for quick warm up (requirement in Section III.1.c) shall be from the start of the test to the time when the average temperature in the bus reaches the minimum temperature, 15 °C (59 °F).

III.b. Ventilation Mode Tests

The purpose of this test is to measure the ventilation mode performance of the CCS.

1) Test Conditions

The test conditions are:

- Doors, windows, and hatches closed,
- No passengers,
- Engine at high idle,
- Bus stationary, and
- Passenger and operator systems in "Vent" mode at maximum settings.

2) Measurements

Calibrated air flow measurements shall be made to determine "Supply", "Return", and "Make Up Air" air flows for the passenger and operator areas after air flows have reached a steady state

condition. Air flow measurements shall be made at the following general locations:

- Supply openings in passenger area above and below the windows,
- Supply openings in passenger area in the foot zone areas,
- Supply openings in operator compartment in the head and foot zones,
- Return openings in passenger area,
- Return openings in operator compartment, and
- Make Up Air (fresh air) intake(s).

3) Requirements

The air flows shall meet the requirements defined in Sections III.2.b.of the CCS Performance Specifications Guidelines.

III.c. Air Distribution Tests

The purpose of this test is to measure the air distribution performance of the CCS.

1) Test Conditions

The test conditions are:

- Windows, hatches, and doors closed,
- CCS in "Heat" mode,
- No passengers,
- Bus stationary,
- Engine at high idle, and
- Passenger and Operator CCS systems at maximum fan settings.

2) Measurements

Air flows shall be made at the following general locations:

- Supply openings in all doorways,
- Supply openings above and below passenger windows,
- Supply openings in the passenger floor zone,
- Supply openings in the operator head and foot zones,
- Return opening(s), and
- Make Up Air (fresh air) intake(s).

3) Requirements

The air flows shall meet the requirements defined in Section III.4 of the CCS Performance Specifications Guidelines.

III.d. Defroster Test

The purpose of this test is to measure the defroster system performance of the CCS.

1) Test Procedure

The windshield defrosting system will be verified by using the SAE Recommended Practice J381, (R) Windshield Defrosting Systems Test Procedure - Trucks, Buses, and Multi-Purpose Vehicles, April 1994.

III.e. Passenger Windows Defogging Test

The purpose of this test is to measure the capability of the CCS to defog the passenger windows.

1) Test Conditions

The test conditions are:

- Cold chamber sufficiently large to adequately perform this test on a bus maintained at or below - 18°C (0°F),
- Vapor generator(s) capable of operating at 1,000 grains/hour per occupant load of the bus,
- Connect equipment allowing temperature measurements of engine coolant and a minimum of five measurements points at 1.4 m (55 inches) above the floor along the longitudinal center line of the bus,
- Set up camera(s) positions at 90 degrees to the test windows,
- Both inner and outer surfaces of the windows shall be thoroughly cleaned, prior to placing the bus in the cold room, using a 3 to 10 percent ammonia-water solution. The window surfaces shall be dried and polished prior to the test,
- Bus parked inoperative with windows, doors, and hatches closed at the start of the test,
- Set CCS thermostat to 21°C (70°F), and
- Engine coolant temperature maintained at 10°C (50°F).

2) Procedures and Measurements

a) The cold chamber shall be maintained at or below the specified test temperature for at least one hour prior to the vehicle soak period.

b) The bus windows must have stabilized at the specified temperatures for a period of not less

than 8 hours. If instrumentation is available to assure that windows are stabilized at the test temperature.

c) The vapor generator(s) placed in the test chamber, but outside the bus are turned on. Operate the vapor generator(s) an adequate amount of time before start of test to ensure water vapor output is at the desired test level (1,000 grains/hour per occupant).

d) Place the vapor generator(s) at the desired locations at 1.4 m (55 inches) above the floor of the bus. Load the test personnel and close all windows, doors, and hatches. Allow the bus to soak for a period of five minutes prior to starting the bus.

e) Start engine and operate bus at 1,200 rpm without opening the doors.

f) Set the CCS to the heat mode at maximum fan speed.

g) Beginning at the start-up of the bus, record the following at 5 minute intervals:

- coolant temperature,
- temperature at five test points,
- mark the extent of the cleared areas of the test windows with a felt marking pencil,
- record these results with a camera (preferred medium is video)

until all test windows have been clear for 15 minutes.

3) Requirements

The time to defog all of the passenger windows shall meet the requirements of Section III.4.d of the CCS Performance Specifications Guidelines.

III.f. CCS Noise Level Test

The purpose of this test is to verify the noise level performance of the CCS.

1) Test Conditions

For the baseline noise tests the conditions shall be:

- Bus parked in an area where the difference between sound levels is more than 10.0 dB (Background versus the Equipment Measured),
- All doors, windows, and hatches are closed,
- Engine running at low idle and at maximum throttle, and
- CCS is off.

For the test the conditions shall be:

- Bus parked in an area where the difference between sound levels is more than 10.0 dB, (Background versus the Equipment Measured),
  All doors, windows and hatches are closed,
  Engine running at same settings as for baseline tests (low idle and maximum throttle), and
- CCS is operating at maximum settings (all CCS modes).

The practices given in SAE J366 are recommended as a general guideline for conducting the noise level measurements.

2) Measurements

Noise level measurements shall be made at the following general locations:

- Operator seat at the center line of seat/steering column, and
- Along the centerline of the bus, as follows;

- Front row of passenger seats,
- Approximate mid point between the doors,
- At seats across from the center door,
- Approximate mid point between center door and rear of the bus, and
- Last row of seats in the bus.

All measurements shall be made at 1200 mm (48 inches), approximately the ear level of a seated adult passenger, in the general locations defined above.

3) Requirements

The noise level differential between the CCS turned off and turned on shall not exceed an overall "A" weighted sound pressure level of 2 dB(A) at any of the measured locations.

III.g. Cooling Tests (Optional)

The CCS cooling performance shall be tested under the requirements defined in Section 5.4.8 of the Standard Bus Procurement Guidelines, Part 5 - Technical Specifications, Baseline Heavy Duty Transit Bus (revised White Book). The test procedures generally used are referred to as the "Houston Pull Down Test".